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**Federal Motor Carrier
Safety Administration**

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REGULATORY IMPACT ANALYSIS AND SMALL BUSINESS ANALYSIS FOR HOURS OF SERVICE OPTIONS

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for the

**Federal Motor Carrier Safety Administration
U.S. Department of Transportation
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LIST OF EXHIBITS

LIST OF ACRONYMS

65 FR 25540	May 2, 2000 Federal Register
AAR	Association of American Railroads
APC	(TTS) America's Private Carriers
APS_Cost	Capital Cost Per Space for Autos
APS_OM	O&M Cost Per Space for Autos
ATA	American Trucking Association
Avg.Rt	Average Response Time
BEA	Bureau of Economic Affairs
BLS	Bureau of Labor Statistics
C	Circadian Component (in 8.3.1)
C	Current Cognitive Capacity (in 8.3.3)
CAS	Circadian Alertness Simulator
CDL	Commercial Drivers License
CFS	1997 Commodity Flow Survey
CMV	Commercial Motor Vehicle
CPCL	Cognitive Performance Capacity Level
CPS	Current Population Survey
DC	Distribution Center
DFACS	Driver Fatigue, Alertness, and Countermeasures Study
DOT	Department of Transportation
ES	Executive Summary
FAF	Freight Analysis Framework
FAID	Fatigue Audit InterDyne Model
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
GDP	Gross Domestic Product
GES	General Estimates System
GRP	Gross Regional Product
H	Homeostatic Component
HHG	Household Goods
HOS	Hours of Service
IIHS	Insurance Institute for Highway Safety
IPI	International Parking Institute
LCM	Logistics Cost Model
LH	Long-Haul
LTL	Less-than-Truckload

M	Circadian Phase Modulating Function
MCIT	The Motor Carrier Industry in Transition
MCMIS	Motor Carrier Management Information System
MM	Million
NAFTA	North American Free Trade Agreement
NAICS	North American Industrial Classification System
NATFD	North American Truck Fleet Directory
NATSO	National Association of Truck Stop Owners
NBER	National Bureau of Economic Research
NERA	National Economic Research Associates
NGA	National Governor's Association
NHS Act	National Highway System Designation Act of 1995
NHTSA	National Highway Traffic Safety Administration
NMCD	National Motor Carrier Directory
NPRM	Notice of Proposed Rulemaking
NREM	Non Rapid Eye Movement
OOIDA	Owner-Operators Independent Drivers Association
OTR	Over the Road
PAB	Performance Assessment Battery
PAR	Police Accident Report
PATT	Parents Against Tired Truckers
PDO	Property Damage Only
Pkg_Amort	Amortization Period for Parking Spaces
Pkg_Life	Average Life of Parking Spaces
PVT	Psychological Vigilance Task
PVT RT	Psychological Vigilance Task Reaction Time Test
Ratio_TD	Ratio of Tractors to Drivers
REM	Rapid Eye Movement
REMI	Regional Economic Models Incorporated
RIA	Regulatory Impact Analysis
SBA	Small Business Administration
SDR	Sleep Dose Response
SH	Short-Haul
SP	Sleep Performance
SPM	Sleep Performance Model
Terminal_Max	Maximum Number of New Trucks at Terminal
Terminal_TD	Drivers Parking at Terminal
TL	Truckload
TOT	Time on Task

TPA_Cost	Capital Cost Per Acre for Trucks
TPA_OM	O&M Cost Per Acre for Trucks
TPA_Ratio	Ratio of Tractor/Trailers Per Acre
Truck_Cap	Cost of Capital (% Return on Assets)
TTS	Transportation Technical Service
UMTIP	University of Michigan Trucking Industry Program
UPS	United Parcel Service
VIUS	Vehicle Inventory and Use Survey
VMT	Vehicle Miles Traveled
VPI	Virginia Polytech Institute
VPI 1	Virginia Tech Field Study
VPI 2	Virginia Tech Focus Group
W	Sleep Inertia Component
WR	Walter Reed
WRAIR	Walter Reed Army Institute of Research
WRAIR-SPM	Walter Reed Army Institute of Research – Sleep Performance Model

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EXECUTIVE SUMMARY: CURRENT RULE AND OPTIONS

This Regulatory Impact Analysis (RIA) provides an assessment of the costs and benefits of potential changes in Department of Transportation Federal Motor Carrier Safety Administration (FMCSA) Hours of Service regulations. The Hours of Service (HOS) regulations address the number of hours that a commercial vehicle driver (CMV) may drive, and the number of hours a CMV driver may be on duty, before rest is required.

The current rules, in broad outline, require CMV operators to take a break of at least 8 consecutive hours or refrain from driving once they have been on duty for 15 cumulative hours, or have driven 10 cumulative hours, since their last 8-hour break. In addition, operators are prevented from driving if they have been on-duty more than 60 hours in the previous 7 days, or 70 hours over 8 days. These regulations, which were developed in the 1930s and have existed in their current form since 1962, are not based on a 24-hour day work cycle, and do not allow sufficient off-duty time for drivers to obtain eight hours of sleep.

The purpose of the proposed action is to improve CMV safety by revising the FMCSA HOS regulations to require motor carriers to provide CMV drivers with better opportunities to obtain sleep. By reducing the incidence of drowsy, tired, or fatigued drivers, FMCSA expects to be able to prevent a significant number of the hundreds of fatalities and thousands of injuries that occur each year on U.S. roads because of fatigued CMV drivers and the crashes in which they are involved.

To that end, this analysis assesses four potential regulatory options. One option is to take no action, keeping the current rules. The other options are referred to as the Parents Against Tired Truckers (PATT) option, the American Trucking Associations (ATA) option, and the FMCSA option, after the groups that developed them. In broad terms, the PATT Option stipulates a 12-hour break after 10 hours of driving and/or a 12-hour working shift, and allows no more than 50 hours of driving or 60 hours on duty over any 7-day period. The ATA Option allows up to 14 hours (and sometimes 16 hours) of driving or other work between 10-hour breaks, and 70 hours on-duty in 7 days. The ATA option's weekly limit on cumulative hours may be exceeded in certain circumstances, through the use of a two-week averaging period, or if the driver takes 34 consecutive hours off. The FMCSA option sets the break after a 14-hour shift at 10 hours, and limits driving to 11 hours between 10-hour breaks. This option allows short haul and local drivers (drivers who sleep at home all evenings and who have limited range of operations) the flexibility to work up to 16 hours for one day per work week. It allows no more than 70 cumulative hours of work in an 8-day period, but allows this count of cumulative hours to be reset to zero if a 32- to 36-hour off-duty break occurs.

This RIA compares the costs and benefits of the options relative to two distinct baselines. Much of the presentation shows the effects of full compliance with the PATT, ATA, and FMCSA options relative to the current rules *under the assumption of 100 percent compliance (termed "Current 100%").* The options also are shown relative to a baseline in which the current rules are in effect, but there is a degree of non-compliance reflecting real-world estimates of existing practices (termed the "Status Quo").

The report is divided into eleven chapters. After an introductory section, Chapter 2 provides an overview of the analysis, sketching out the methods that are used to estimate costs and benefits. Chapter 3 profiles the affected industry, in its qualitative characteristics and in terms of quantitative measures. Chapter 4 presents the options in greater detail. Chapter 5 explains in detail the methods used to estimate the effects of the options on industry operations. Chapter 6 then explains how these changes in operations were translated into changes in cost, Chapter 7 lays out the effects on the mode split between truck and rail, and Chapter 8 explains the translation of the operational changes into benefits. The calculation of net costs and benefits is presented in Chapter 9, Chapter 10 presents impacts on carriers (with emphasis on small entities), and impacts on the economy as a whole are presented in Chapter 11.

ES.1 Approach to Analysis

The cost analysis is based on a broad understanding of current patterns of driving, assessments of the changes in those patterns that would be needed to comply with various options, and the resulting impacts on the cost of employing and equipping drivers. Long-haul and regional operations ("long-haul" or LH for short) and local or short-haul operations (referred to as "short haul" or SH) are examined separately. In contrast to long-haul operations, short-haul operations are characterized by drivers who spend each night at home and by a limited range of operations of less than 150 miles. In both cases, the characteristics of the operations were based on surveys and existing studies, supplemented by conversations with individuals familiar with the industry.

ES.2 Long-Haul Cost Analysis

The cost analysis of LH operation started with data on the distribution of hours spent driving and working by LH drivers. Analysis of the data on patterns of work and rest among LH drivers showed a range of levels of work effort relative to existing HOS rules. Though a substantial fraction of operations stayed well within the daily and weekly rules, many operations appeared to stay just within the rules, and another substantial fraction exceeded them. To assess the effects of the options on the most intense operations, which are most likely to be affected by compliance with existing rules or new options, operations were simulated using commercially available routing software. This software was designed to select efficient routes for delivering realistic sets of orders, while staying within HOS-based constraints that mirrored the options. For-hire truckload carriers and private fleets with operations of different lengths, in different regions, and on different scales were examined. The essential outputs from these simulations consisted of driver productivity measures and patterns of schedule changes over time (i.e., the extent to which drivers could hold to a favorable daily pattern of work and rest).

The measures of driver productivity, combined with a basic assumption (later relaxed) that total industry output would be constant, led directly to estimates of the required percentage change in the number of drivers the affected industry segment would need. Changing the *number* of drivers was found to affect costs despite the assumption that the aggregate amount of work done by the drivers would not change. These cost changes came about largely because replacing extra hours of work by existing drivers with the same amount of work from newly hired drivers is not an equal exchange: there are significant implications for fringe benefits, support staff, and average wage rates, when the same amount of work is spread over more drivers. The magnitude of these effects was calculated based largely on labor market data from the Bureau of Labor Statistics (BLS) and the motor carrier industry. In addition to the net costs of shifting hours of work from existing to new drivers, we also took into account the fact that overall wages for truck drivers may have to rise slightly to draw enough new drivers into the industry.

In addition to changes in employee costs, we estimated the changes in several other important cost categories. Changes in fleets of tractors and trailers that would be needed to support the increase in drivers were estimated, and a pattern of net purchases over time was assumed, given that each vehicle in the larger fleet would be used slightly less per year if total shipments did not change. We also estimated the changes in parking spaces, insurance, and maintenance that would be needed to support the larger fleet, again taking into account the effects of lower annual miles per vehicle.

Due to the competitive nature of the motor carrier industry, higher costs for labor and other inputs were assumed to be passed on to shippers in the form of rate increases. The effects of these higher rates on the split between truck and rail was estimated using a logistics cost model.

ES.3 SHORT-HAUL COST ANALYSIS

The analysis of the impacts on SH operations paralleled that for LH operations except for the method used to predict the direct effects on operations and labor productivity. The SH analysis was based on survey data on the average daily and weekly hours of driving and work across a variety of types of operations, combined with data on the variability in those averages. Analysis of the data showed that the daily limits on total hours worked would be the dominant effect of the options. We constructed a distribution of daily hours of work based on a combination of two sets of survey data on SH drivers and used it to predict what fraction of all work hours would have to be reallocated to newly hired drivers under various HOS options. The costs of these shifts in hours of work then were estimated in the same way as for the LH analysis.

ES.4 ANALYSIS OF SAFETY BENEFITS

The benefits of the HOS options were estimated using a multi-step process to relate changes in HOS rules to changes in crash experience and results. Conceptually, we took the following steps for each option:

- Constructed a set of sample working and driving schedules of different intensities and degrees of regularity;

- Used the results of the modeling performed for the cost analysis to determine the percentages of drivers following each sample schedule, and to determine the shifts in these percentages caused by different HOS options;

- Translated the amount of on-duty time in each schedule into expected amounts of sleep, using a function based on an existing field study of truck drivers;

- Used a version of the Walter Reed Army Institute of Research Sleep Performance Model (WRAIR-SPM) to estimate the effects of different sleep and driving schedules on a measure of alertness;

- Translated changes in alertness into relative changes in crash risks on the basis of an existing laboratory study of performance on a driving simulator;
- Calibrated the results of the modeling of simulated crash risks to the real world using independent estimates of the total numbers and percentages of crashes attributable to fatigue; and
- Translated the estimated changes in fatigue-related crashes into dollar values for avoided crashes using existing estimates of the damages caused by truck crashes.

After calculating the benefits of the options, their estimated costs were subtracted to yield estimates of the net benefits of each compared to the current rules with full compliance and compared to the status quo situation.

ES.5 BROADER ECONOMIC IMPACTS

In addition to calculating the social costs, benefits, and net benefits of the options, the analysis also considered the impacts on the carriers, and on the economy as a whole. The changes in labor productivity, costs for labor and other inputs, and changes in the mode split between truck and rail were disaggregated to six regions and fed into the REMI regional economic model (developed by Regional Economic Models Incorporated). The model's outputs give an approximate picture of the relative effects of the options on economic growth and employment across the country.

ES.6 RESULTS

Exhibits ES-1 and ES-2 show the results of the analysis of the changes in industry operations that would result from compliance with the current rules and the options. ES-1 shows the effects of the current rule and the options, assuming full compliance, relative to the status quo (in which not all drivers comply with the HOS rules). The exhibit shows the percentage increase in drivers that would be needed to make up for the lower number of hours that drivers could work, relative to the status quo. Also shown are the absolute numbers of additional driver that would be needed.

Exhibit ES-2 shows the differences between the options and the current HOS rules under full compliance: the PATT option would require more drivers than the current rules, while the ATA option would require fewer. The FMCSA option would require more drivers for SH operations, but fewer overall (due to the greater efficiency it would allow in LH operations).

Exhibit ES-1
Changes in Drivers Needed in Response to HOS Limits, Relative to the Status Quo

		Current/ 100%	PATT	ATA	FMCSA
Percentage Change	**LH**	**8.1%**	**12.1%**	**2.8%**	**4.2%**
	SH	**0.7%**	**8.4%**	**0.3%**	**1.4%**
Numbers	LH	121,500	181,500	42,000	63,000
	SH	10,800	126,300	4,800	21,300
	Total	**132,300**	**307,800**	**46,800**	**84,300**

Source: Exhibit 9-13.

Exhibit ES-2
Changes in Drivers Needed in Response to HOS Limits,
Relative to Current Rules with Full Compliance

		PATT	ATA	FMCSA
Percentage Change	**LH**	**4.0%**	**-5.3%**	**-3.9%**
	SH	**7.7%**	**-0.4%**	**0.7%**
Numbers	LH	60,000	-79,500	-58,500
	SH	115,500	-6,000	10,500
	Total	**175,500**	**-85,500**	**-48,000**

Source: Exhibit 9-1.

Exhibit ES-3 shows the results of the cost analysis for the options relative to the current rules with full compliance. The PATT option would be more expensive to comply with than current rules, especially for SH operations, while the ATA option would be less expensive. The FMCSA option would be more expensive for SH operations, though it would be less expensive overall due to its savings for LH operations.

The basis of the benefits analysis is the estimation of the total number of crashes involving vehicles subject to the rule, the damages imposed by those crashes, and the assessment of the percentage of those crashes and damages attributable to fatigue. The total crashes and damages are presented in Exhibit ES-4. Of these crashes, an estimated 8.1 percent result from fatigue. Thus, the total damages from fatigue-related crashes have a value of about 8 percent of $32 billion, or about $2.5 billion per year. Excluding a fraction of crashes that occur in operations that would be little affected by the changes in the HOS rules, the fatigue-related crashes subject to the options are estimated to impose costs of about $2.3 billion per year.

Exhibit ES-3
Direct Cost Changes Relative to Current Rules with Full Compliance
(millions of dollars per year)

Cost Category		PATT	ATA	FMCSA
LH	Driver Labor Cost	287	-792	-636
	Other Costs	478	-563	-437
	Total Costs	**764**	**-1,356**	**-1,073**
SH	Driver Labor Cost	1,557	-38	90
	Other Costs	1,038	-49	78
	Total Costs	**2,595**	**-87**	**168**
Total	**Total Costs**	**3,360**	**-1442**	**-905**

Source: Exhibits 9-2, 9-3, 9-4. Totals may not add due to rounding.

The analysis of the effects of the rules and options on crash risks showed that these damages could be reduced substantially.

Exhibit ES-4
Calculation of Total Value of Large Truck Crashes by Year

	Average per Year
Fatal Crashes	4,568
Injury Crashes	92,000
Property Damage Only Crashes	329,250
Total Large Truck Crashes	425,818
Average Damages per Large Truck Crash	$75,637
Total Damages from Large Truck Crashes (millions)	$32,208

Source: Exhibit 8-13.

Exhibit ES-5 shows the estimated percentage of crashes related to fatigue under the current rules, the options, and the status quo. As shown, the percentage of fatigue-related crashes is substantially higher in LH than in SH operations. Similarly, the changes in fatigue-related crashes attributable to the options are greater in LH than in SH. These differences result from the more arduous schedules that LH drivers currently have, and from the effects of the rules and options on those schedules.

The values from Exhibit ES-5, compared to one another and adjusted for the effects of new drivers and mode shifts, can be used to find the total benefits of the options. These benefits can then be compared to costs to yield the net benefits of the options.

Net benefits of the options relative to the current rules with full compliance are shown in Exhibit ES-6. This exhibit breaks the net benefits down by length of haul, highlighting the fact that the HOS rules are more cost-effective in their application to LH than SH operations.

Exhibit ES-5
Annual Damages Attributable to Fatigue by Option

		Current/ 100%	PATT	ATA	FMCSA	Status Quo
LH	Percentage of Crashes Attributable to Fatigue	8.5%	6.2%	10.2%	7.1%	11.2%
	Total Damages of Fatigue-related Crashes (millions)	$1,361	$997	$1,628	$1,138	$1,791
SH	Percentage of Crashes Attributable to Fatigue	3.8%	3.5%	3.8%	3.7%	3.9%
	Total Damages of Fatigue-related Crashes (millions)	$506	$470	$514	$492	$528
All	Total Damages of Fatigue-related Crashes (millions)	$1,867	$1,467	$2,142	$1,630	$2,319

Source: Exhibit 8-15.

Exhibit ES-6
Net Benefits by Length of Haul Relative to Current Rules with Full Compliance
(millions of dollars per year)

		PATT	ATA	FMCSA
LH	Total Benefits	374	-269	225
	Total Cost	764	-1,356	-1,073
	Total Net Benefits	**- 390**	**1,087**	**1,298**
SH	Total Benefits	-34	-4	4
	Total Cost	2,595	-87	168
	Total Net Benefits	**-2,629**	**83**	**-164**
All	**Total Net Benefits**	**-3,019**	**1,170**	**1,133**

Source: Exhibit 9-11.

The ATA option provides net benefits in both LH and SH operations, though its net benefits are much greater in LH. Similarly, the PATT option has much smaller net costs in LH than in SH operations, and the FMCSA option has net benefits in LH that are partially offset by its net SH costs.[1]

A brief assessment was made of a variant of the FMCSA option that would permit less flexibility in SH operations. This variant would not allow SH drivers to work one 16-hour shift per week, in place of one of the 14-hour shifts. Examining this variant allows us to assess the effects of allowing this flexibility in the FMCSA proposal and the lower cost-effectiveness of restrictions on SH operations.

The analysis showed that this change would increase the annual costs of the FMCSA option relative to the current rules with full compliance by about three-fold, from $164 million to about $646 million, or an increase of almost $500 million per year. The majority of these costs result from the short-haul segment of operations. These additional costs would translate almost directly into a reduction in net benefits because the effects of the reduced flexibility on crashes would be very small. We estimate that, because the increase in the need for new SH drivers would more than offset the slight reduction in fatigue-related accidents, prohibiting 16-hour shifts would worsen the crash-reduction benefits slightly: total benefits would fall by about $10 million per year, and fatalities would rise by one or two per year.

The analysis of the economy-wide changes revealed that, as expected for a set of rules that has moderate effects on an industry that itself is only one component of the economy, the options would cause changes well within a tenth of a percent of total employment, GDP, prices, and disposable income. Impacts on carriers were more noticeable, with the PATT option imposing net costs and the other options having small positive effects on net income and profitability.

[1] Note that none of the options show positive benefits in SH operations, despite reducing fatigue-related crashes to some degree. The reductions in the fatigue-related SH crashes are outweighed by the increased risks associated with new, inexperienced drivers in that industry segment.

1. BACKGROUND

This Regulatory Impact Analysis (RIA) provides an assessment of the costs and benefits of potential changes in Department of Transportation Federal Motor Carrier Safety Administration (FMCSA) Hours of Service regulations. The Hours of Service (HOS) regulations address the number of hours that a commercial vehicle driver (CMV) may drive, and the number of hours a CMV driver may be on duty, before rest is required, as well as the minimum amount of time that must be reserved for rest. The current HOS regulations were promulgated pursuant to the Motor Carrier Act of 1935 and are codified at 49 CFR 395.

Revisions to the HOS regulations were proposed in a Notice of Proposed Rulemaking (NPRM) published in the May 2, 2000 Federal Register (65 FR 25540). Responding to questions raised about the proposals, Congress directed the Department of Transportation not to issue a final rule in Fiscal Year 2000. Following reviews of the comments on the NPRM and additional study, the Federal Motor Carrier Safety Administration (FMCSA) developed revised options for changes in the HOS rules. FMCSA sought an independent assessment of the various options to determine their costs and benefits. This analysis was conducted consistent with the requirements of Executive Order 12886, which requires analysis of the costs and benefits of significant regulatory actions.

1.1 PURPOSE AND NEED FOR PROPOSED ACTION

The proposed action is for the FMCSA to revise its HOS regulations. The HOS regulations apply to motor carriers (operators of CMVs) and CMV drivers, and regulate the number of hours that CMV drivers may drive, and the number of hours that CMV drivers may remain on duty, before a period of rest is required. The current regulations are divided into "daily" and "multi-day" provisions, which can be expressed as follows:

- Operators can cumulatively drive up to 10 hours or be on duty up to 15 hours since the end of their last 8-consecutive-hour break.[2]
- Operators can cumulatively drive or be on-duty up to 60 hours over the last 6 consecutive 24-hour periods plus the current 24-hour period, or 70 hours over the last 7 24-hour periods plus the current 24-hour period.

The HOS regulations were originally promulgated in 1937, and the last significant revision to the regulations was in 1962. Several categories of motor carriers and drivers are exempt from parts of the HOS regulations or from the entire HOS regulation under the National Highway System Designation Act of 1995 (referred to as the NHS Act).

1.1.1 Purpose of the Proposed Action

The purpose of the proposed action is to improve CMV safety by revising the FMCSA HOS regulations to require motor carriers to provide CMV drivers with better opportunities to obtain

[2] To be more exact, drivers cannot drive after they have been on-duty 15 cumulative hours after their last 8-consecutive-hour break.

sleep, in order to reduce the incidence of drowsy, tired, or fatigued drivers and the crashes in which they are involved.

The proposed action is necessary because the FMCSA estimates that hundreds of fatalities and thousands of injuries occur each year on U.S. roads because of fatigued CMV drivers. The current HOS regulations are not based on a 24-hour day work cycle, and do not allow sufficient off-duty time for drivers to obtain eight hours of sleep. The HOS regulations have existed in their current form since 1962. Since that time significant changes in highways, equipment, and transit time demands have occurred. The high volume and speed of CMV operations on Interstate highways and the higher traffic conditions in local and regional environments require a high level of driver alertness. Also, the results of scientific studies into fatigue causation, sleep, circadian rhythms, night work, and other relevant matters were not available when the current HOS regulations were developed. Therefore there is a need for the current FMCSA HOS regulations to be reevaluated.

1.2 OPTIONS

This analysis considers and assesses the potential environmental consequences of four potential regulatory options. One option is to take no action, keeping the current rules. The other options are referred to as the Parents Against Tired Truckers (PATT) option, the American Trucking Associations (ATA) option, and the FMCSA option, after the groups that developed them. The options and the rationale behind their provisions are described briefly in this section, with more complete treatment in Chapter 4.[3]

1.2.1 Current Rules

The Current Rules option is the continued implementation of the current HOS regulations, with no additional rulemaking and no changes in the method of implementation of the current HOS regulations. Under this option, the HOS rule proposed by the FMCSA in the May 2, 2000 NPRM would be withdrawn and no new rule would be promulgated. The FMCSA would continue to enforce the current HOS regulations. The existing exemptions to the current HOS regulations under the NHS Act would remain in effect.

The current HOS regulations are divided into "daily" and "multi-day" provisions. The daily and multi-day provisions of the current regulations can be expressed as:

- Operators can cumulatively drive up to 10 hours and/or be on-duty up to 15 hours since the end of their last eight-consecutive-hour break.[4]
- Operators can cumulatively drive or be on-duty up to 60 hours over the last six consecutive 24-hour periods plus the current 24-hour period, or 70 hours over the last seven 24-hour periods plus the current 24-hour period.

[3] The provisions described for these options refer directly to solo drivers; there are some differences for "team drivers" which were not analyzed for this report on the grounds that the differences between the rules would be unlikely to have significant effects on team drivers.

[4] To be more exact, drivers cannot drive after they have been on-duty 15 cumulative hours after their last 8-consecutive-hour break.

1.2.2 PATT Option

This option is based on recommendations from the organization Parents Against Tired Truckers.

The PATT option is divided into "daily" and "multi-day" provisions. These can be expressed as:

- Operators can cumulatively drive up to ten hours or be on-duty up to 12 hours since the end of their last 12-consecutive-hour break.

- Operators can cumulatively be on-duty up to 60 hours and/or drive up to 50 hours over the last six consecutive 24-hour periods before the beginning of the current 24-hour period,[5] plus the current 24-hour period.

1.2.3 ATA Option

This option is based on recommendations from the American Trucking Associations. It is divided into "daily" and "multi-day" provisions which can be expressed as follows:

- Operators can drive or be on duty 14 cumulative hours. Operators are allowed up to 16 cumulative hours (up to two hours of "flex time") twice per seven-day period as long as each extended day is followed by a day in which the number of hours worked is offset by an equivalent number of hours; the cumulative on-duty period must be followed by a ten-hour off-duty period. These hours are cumulative on-duty hours and are not inclusive of any off duty breaks.

- Operators can generally drive or be on duty 70 hours over the last seven 24-hour periods or 140 hours over the last 14 24-hour periods.

- Operators who obtain 34 consecutive hours of off-duty time can begin a new seven-day period, over which they can be drive or be on duty a cumulative total of 70 hours (i.e., the seven-day "clock" is restarted by a 34-hour off-duty period).

1.2.4 FMCSA Option

This option was developed by FMCSA. The FMCSA option is divided into daily and multi-day provisions, which can be expressed as follows:

- Operators can drive up to 11 hours within a period of 14 consecutive hours from the start of the duty tour, followed by a break of ten consecutive hours.

- Short-haul operators can be on-duty up to 16 consecutive hours one day during a seven-day work week so long as two such days do not occur consecutively.

- Operators can cumulatively drive or be on-duty up to 60 hours over the last six consecutive 24-hour periods plus the current 24-hour periods or 70 hours over the last 7 24-hour periods plus the current 24-hour period.

[5] Note that in all alternatives, 24-hour time-periods for drivers are established by the carrier by terminal

- Operators who obtain 34 consecutive hours of off-duty time can begin a new seven-day period, over which they can be drive or be on duty a cumulative total of 70 hours (i.e., the seven-day "clock" is restarted by a 34-hour off-duty period).[6]

1.3 Baselines for the Analysis

This RIA compares the costs and benefits of the options relative to two distinct baselines. Much of the presentation shows the effects of full compliance with the PATT, ATA, and FMCSA options relative to the current rules *under the assumption of 100 percent compliance.* This approach ensures that the full effects of the options' provisions on costs and benefits are captured. On the other hand, because there is evidence that drivers do not always comply with the existing rules, it is important to compare the proposed options against the current rules at an estimated level of current compliance or "Status Quo." Thus, the options are also shown relative to a baseline in which the current rules are in effect, but there is a degree of non-compliance reflecting real-world estimates of existing practices. In long-haul operations, this degree of non-compliance was estimated to result in about eight percent more hours worked than would be allowed under current rules, while in short-haul operations non-compliance was estimated to result in less than one percent too many hours worked.[7]

These two baselines are distinguished in this report by referring to the current rules with 100 percent compliance as "Current-100%," and the current rules with existing compliance levels as the "Status Quo" scenario.

1.4 Remaining Sections of the Report

The remainder of this report is divided into ten chapters. Chapter 2 provides an overview of the analysis, sketching out the methods that are used to estimates costs and benefits. Chapter 3 profiles the affected industry, in its qualitative characteristics and in terms of quantitative measures of firm sizes and the like. Chapter 4 presents the options in greater detail. Chapter 5 explains in detail the methods used to estimate the effects of the options on industry operations. Chapter 6 then explains how these changes in operations were translated into changes in cost, Chapter 7 lays out the effects on the mode split between truck and rail, and Chapter 8 explains the translation of the operational changes into benefits. The calculation of net costs and benefits is presented in Chapter 9, Chapter 10 presents impacts on carriers (with emphasis on small entities), and impacts on the economy as a whole are presented in Chapter 11.

[6] The choice of the span of the off-duty period that would allow a restart under this option had not been decided upon at the time of this analysis, but it would be between 32 and 36 hours.

[7] These estimates are presented in Exhibit 9-13. The estimates of the excess hours worked by long-haul drivers are based on the discussion in Appendix C, section C.2, and the estimate for short-haul drivers is discussed in section 5.2.

2. OVERVIEW OF THE ANALYSIS

This chapter lays out the main steps in the analysis of the costs and benefits of the HOS options, along with the main sources of data used for the steps. The analysis of costs is presented first, followed by the analysis of benefits and other impacts. The presentation also covers short-haul operations separately from long-haul operations, especially in the area of costs.

2.1 Analysis of the Costs of the HOS Options

The cost analysis is based on a broad understanding of current patterns of driving, assessments of the changes in those patterns that would be needed to comply with various options, and the resulting impacts on the cost of employing and equipping drivers. Long- and short-haul operations are examined separately, because the patterns of work and sleep differ considerably between the two. In both cases, the characteristics of the operations were based on surveys and existing studies, supplemented by conversations with individuals familiar with the industry.

2.1.1 Long-Haul Analysis

As used in this report, the term "long-haul" encompasses both long-haul and what most truckers would call regional, operations: those with average lengths of haul greater than 150 miles. "Short-haul" covers local and short-haul operations, those with average lengths of haul less than 150 miles. These operations may be either for-hire, or private, carriers.

Long-haul operations often require multi-day trips in which drivers spend multiple nights away from home. Substantial portions of their time is spent driving, though loading, unloading, and waiting time are also factors. The cost analysis of long-haul drivers starts with data on the distribution of hours spent driving and working by long-haul drivers. Data from driver surveys is the most important source, with additional information coming from databases on motor carrier characteristics, HOS violations, and labor markets.

Analysis of the data on patterns of work and rest among long-haul drivers showed a range of levels of work effort relative to existing HOS rules. Though a substantial fraction of operations stayed well within the daily and weekly rules, many operations appeared to stay just within the rules, and another substantial fraction exceeded them. Our analysis concentrated on the fraction of operations that equaled or exceeded the current HOS rules, on the assumption that the rest of the industry would be affected to a much smaller degree by changes in the rules.

To assess the effects of the options on these intense operations, which are most likely to be affected by compliance with existing rules or new options, we simulated their operations using commercially available routing software. This software was designed to select efficient routes for delivering realistic sets of orders, while staying within HOS-based constraints that mirrored the options. For-hire truckload carriers and private fleets with operations of different lengths, in different regions, and on different scales were examined. The essential outputs from these simulations consisted of driver productivity measures and patterns of schedule changes over time (i.e., the extent to which drivers could hold to a favorable daily pattern of work and rest).

The measures of driver productivity, combined with a basic assumption (later relaxed) that total industry output would be constant, led directly to estimates of the required percentage change in the number of drivers the affected industry segment would need. Changing the *number* of drivers was found to affect costs despite the assumption that the aggregate amount of work done by the drivers would not change. These cost changes came about largely because replacing extra hours of work by existing drivers with the same amount of work from newly hired drivers is not an equal exchange: there are significant implications for fringe benefits, support staff, and average wage rates, when the same amount of work is spread over more drivers. The magnitude of these effects was calculated based largely on labor market data from the Bureau of Labor Statistics (BLS) and the motor carrier industry. In addition to the net costs of shifting hours of work from existing to new drivers, we also took into account the fact that overall wages for truck drivers may have to rise slightly to draw enough new drivers into the industry.

In addition to changes in employee costs, we estimated the changes in several other important cost categories. Changes in fleets of tractors and trailers that would be needed to support the increase in drivers were estimated, and a pattern of net purchases over time was assumed, given that each vehicle in the larger fleet would be used slightly less per year if total shipments did not change. We also estimated the changes in parking spaces, insurance, and maintenance that would be needed to support the larger fleet, again taking into account the effects of lower annual miles per vehicle.

Due to the competitive nature of the motor carrier industry, higher costs for labor and other inputs were assumed to be passed on to shippers in the form of rate increases. The effects of these higher rates on the split between truck and rail was estimated using a logistics cost model.

2.1.2 Short-Haul Analysis

The analysis of the impacts on short-haul operations paralleled that for long-haul operations except for the method used to predict the direct effects on operations and labor productivity. The short-haul analysis was based on survey data on the average daily and weekly hours of driving and work across a variety of types of operations, combined with data on the variability in those averages. Analysis of the data showed that the daily limits on total hours worked would be the dominant effect of the options. We constructed a distribution of daily hours of work based on a combination of two sets of survey data on short-haul drivers, and used it to predict what fraction of all work hours would have to be reallocated to newly hired drivers under various HOS options. The costs of these shifts in hours of work were then estimated in the same way as for the long-haul analysis.

2.2 Analysis of Safety Benefits

The benefits of the HOS options were estimated using a multi-step process to relate changes in HOS rules to changes in crash experience and results. Conceptually, we took the following steps for each option:

- Constructed a set of sample working and driving schedules of different intensities and degrees of regularity;

- Used the results of the modeling performed for the cost analysis to determine the percentages of drivers following each sample schedule, and to determine the shifts in these percentages caused by different HOS options;

- Translated the amount of on-duty time in each schedule into expected amounts of sleep, using a function based on a field study of truck drivers;

- Used a version of the Walter Reed Army Institute of Research Sleep Performance Model (WRAIR-SPM) to estimate the effects of different sleep and driving schedules on a measure of alertness;

- Translated changes in alertness into relative changes in crash risks on the basis of a laboratory study of performance on a driving simulator;

- Calibrated the results of the modeling of simulated crash risks to the real world using independent estimates of the total numbers and percentages of crashes attributable to fatigue; and

- Translated the estimated changes in fatigue-related crashes into dollar values for avoided crashes using existing estimates of the damages from fatal, injury, and property-damage only crashes.

Some detail on these steps is presented here, concentrating on the approach used for long-haul drivers. Additional explanations are contained in Chapter 8 and Appendix G.

2.2.1 Construction of Working and Driving Schedules

In the first step of the benefits estimation process, we reviewed survey data (described in Appendix B) on the numbers of days per week and hours per day worked and driven by truck drivers. These data were used to construct a range of sample working and driving schedules for drivers under existing conditions, and to estimate the percentage of drivers whose typical work weeks could be represented by each schedule. An important aspect of these sample schedules was the degree to which the hours of work and hours off-duty kept to a regular pattern, as opposed to "rotating" over the course of a week or two.

2.2.2 Estimating Shifts in the Driving Schedules

In the second step, the results of the simulation of carrier operations (described above under the cost analysis) were used to determine the effects of the options on the drivers' schedules. For each option, simulation results on the changes in average hours worked, and option-by-option limits on permitted hours of work, were used to re-estimate the percentages of drivers who could be represented by each sample schedule. The simulation results were also used to estimate the degree to which drivers' schedules could be expected to "rotate" throughout a week, with the starting times of the work shifts and layovers changing from day to day.

2.2.3 Estimating Effects on Sleep

The survey data and simulation results provided information on drivers' total time on-duty per day, but did not directly show quantities of sleep for specific schedules. To translate on-duty hours to quantities of sleep, we used data on reported duty hours and measured sleep from a field study of long-haul truck drivers to determine the extent to which extra hours of work cut into sleep. Another set of data, from a survey of truck drivers, was used to quantify the relationship between the time of day during which a driver sleeps and the amount of sleep he or she is able to get.

2.2.4 Effects of Sleep and Work Schedule Changes on Alertness

Sleeping and working schedules were translated into predicted levels of alertness using a slightly modified version of the WRAIR-SPM. This model was designed to predict the effects of changes in sleep and time of day on alertness as manifested in a measure of reaction time on the psychomotor vigilance task (PVT). By comparing predicted alertness levels for drivers following each of the sample schedules to alertness levels for drivers with ideal sleep and work schedules, we were able to measure the decrease in alertness (and therefore the increase in fatigue) resulting from each sample schedule. The degree to which the schedules allowed the drivers to drive and sleep at appropriate times, as opposed to forcing them to adjust rapidly to shifting sleep and work schedules, turned out to have a substantial effect on the degree of fatigue associated with the schedules.

2.2.5 Effects of Fatigue on Crash Risks

Using data from a laboratory experiment conducted using truck drivers by the Walter Reed Army Institute of Research, the changes in alertness were used to project relative changes in simulated crashes. The simulations essentially excluded scenarios in which drivers of other vehicles made errors that caused crashes. We therefore interpreted the changes in simulated crash risks as corresponding to the subset of truck crashes in which the truck driver was judged to be at fault. This assumption is conservative (i.e., tending to reduce the estimated effects of fatigue) because even in cases in which another drive is "at fault," a fatigued truck driver may be less able to avoid the crash than a well-rested driver.

2.2.6 Calibration of Modeled Fatigue Crash Results to Actual Fatigue Crashes

Because the measure of crash risks in different sleep schedules was based only on performance in driving simulators, the results of the modeling could not be used directly to predict changes in actual crashes. Instead, we developed an independent estimate of the total numbers and percentages of all truck crashes that could be attributed to fatigue under current rules and conditions. This estimate was based on examinations of databases on fatal and non-fatal crashes that included assessments of the causes of the crashes. We focused on fatal crashes in which fatigue or inattention were listed as contributing to the crash. Slightly more than a fifth of the crashes attributed to inattention were counted as fatigue-related on the basis of a study of the causes of inattention.

These independent estimates of the numbers and percentages of crashes that could be attributable to fatigue were then used to calibrate the results of the modeling of simulated crashes to ensure that the overall magnitude of the model results were realistic. To summarize, a version of the WRAIR-SPM was used to estimate the relative increase in fatigue-related crashes for each of a large number of sample working schedules; these relative increases were adjusted to create estimates of changes in actual crashes for each schedule; and then the effects of the different HOS options on the fraction of drivers represented by each sample schedule was factored in to determine the differences in actual numbers of crashes by option.

2.2.7 Values of Changes in Crashes

Changes in crashes were valued by using data bases on recent crashes to divide them into fatal crashes, crashes with injuries but no fatalities, and crashes with property damage only. These individual types of crashes were valued on a per-crash basis using research by Miller and Zaloshnja following methods for valuation that are standard for Department of Transportation studies.

2.3 BROADER ECONOMIC IMPACTS

Finally, the changes in labor productivity, costs for labor and other inputs, and changes in the mode split between truck and rail were disaggregated to six regions and fed into the REMI regional economic model (developed by Regional Economic Models Incorporated). The model's outputs give an approximate picture of the relative effects of the options on economic growth and employment across the country.

3. PROFILE OF THE MOTOR CARRIER INDUSTRY

3.1 GENERAL INDUSTRY DESCRIPTION

In this chapter, we describe the trucking industry. We sub-divide the industry into its principal segments, describe their basic operating characteristics, and provide some data on the size and level of activity of the various segments. The principal sub-divisions of the industry, together with associated revenue and VMT estimates for 2000 are shown in Exhibit 3-1 on the following page. More detailed data on the industry are in Appendix A, together with detailed descriptions of the way in which quantitative estimates of industry characteristics were developed.

3.1.1 Industry Segments

There are, perhaps, three major lines of division within the industry. One is between long-haul and short-haul: between companies that provide primarily intercity services and companies that provide service within a metropolitan region and its outlying areas and perhaps to nearby cities. Second, there is the divide between the for-hire and private-carriage segments. The former are the firms that move the goods of others for payment—probably what most people think of as the "trucking industry." The latter are firms that use their own trucks and drivers to move their own goods. When their trucks are returning empty, many private carriers will move the goods of others for hire; some will not. The for-hire segment is split into two principal classes: truckload (TL) and less-than-truckload (LTL). TL carriers move truckloads of goods direct from origin to destination. LTL carriers consolidate, haul, and distribute goods through a network of terminals in less-than-truckload lots. These segments are discussed below in greater detail.

Long-haul and Short-haul

One major division within the industry is between long-haul and short-haul. Selecting a point of demarcation is inherently somewhat arbitrary. We have chosen 150 miles as the length of haul that is the border between short haul and long haul. More precisely, if a company has an average length of haul less than 150 miles, we consider it to be in short-haul service; with an average length of haul in excess of 150 miles, it is in long-haul service. A point of terminology is useful here. Many industry observers will speak of local and short-haul carriage with some sense of distinction between them, the latter having longer moves. When we refer to short-haul with no other qualification, we include both local and short-haul. Most truckers make a clear distinction between regional and long-haul operation, the latter having the longer runs. Again, in an unqualified reference to long-haul we include both long-haul and regional.

In the trucking business, a regional move is generally one of 500 miles or less, and a company calling itself regional would have average haul under 500 miles or even a maximum of 500 miles. Many in the trucking business think of regional as next-day delivery, a maximum of 500 miles. For reasons relating to analysis of operational impacts of rule changes, explained in Chapter 5, we have distinguished between short regional and long regional operations, the latter with a maximum average haul of 700 miles. On an average length-of-haul basis, we classify firms as follows:

Exhibit 3-1
2000 Revenue and VMT Estimates by Industry Segment
(billions of VMT and dollars (2000))

	For-hire						Private	
	Truckload (TL)		Less-than-truckload (LTL)		Other			
Long-haul and regional	Revenue 97	VMT 77	Revenue 27	VMT 8	Revenue 31	VMT NA	Revenue 123	VMT 81
Short-haul and local	Revenue 76 VMT 30						Revenue 122	VMT 50

Sources: The estimates in this table are derived from a variety of data sources. Detailed explanations of the development of the estimates are in Appendix A.

Note on LTL and Other Estimates: LTL revenue figures include, for the most part, local pick-up and delivery operations. Other is package service and household goods. Package service also includes pick-up and delivery. For reasons explained later, the LTL and package revenue and VMT numbers were not used in the benefit-cost analysis. Revenue estimates are provided here simply to give a complete picture. Most of the revenue in Other is in packages ($24 billion), with approximately $7.0 billion for household goods firms. The role of these firms in the analysis is more fully discussed in Chapter 5.

Note on short-haul and local for-hire revenue and VMT: These estimates derive from an estimate of intrastate and local revenue that did not distinguish between various types of for-hire service. Some package and LTL activity is reflected in these figures.

Short-haul:		less than 150 miles
Long-haul:	short regional:	150 to 300 miles
	long regional:	300 to 700 miles
	long-haul:	more than 700 miles.

For-hire Service

The major division is between truckload (TL) and less-than-truckload (LTL) service. The distinction is a simple one. A truckload firm moves a shipment, a full truckload, or close to it, directly from origin to destination. A LTL operation collects small shipments from local pick-ups, moves them over the road between terminals in truckloads, breaks them up at the destination terminal, whence it makes local deliveries. For-hire firms also include household goods and parcel-delivery firms. These latter categories are not in the focus of this chapter. Their place in the analysis is more fully addressed in Chapter 5.

Truckload companies

Total TL revenue is about $110 billion, of which about $97 billion is from long-haul service. These firms own about 770,000 tractors, or perhaps more; of these, 650,000 to 670,000 are in long-haul service. (As explained in the next section, these numbers are necessarily approximations.)

There are approximately 55,000 for-hire trucking firms (excluding owner-operators working under lease), and almost all of them are TL companies. This is a stark contrast with the LTL sector where there are fewer than 1,000 firms and almost all the business is with fewer than 40 firms.

At a rough approximation, there are around 52,000 or 53,000 TL firms. Of these, 40,000 are very small, with five or fewer tractors. This group is the owner-operators, those that are genuinely independent firms with their own customers. There are somewhere around 300,000 owner-operators in total, but the great preponderance of them are working under leases to larger TL companies. They are, in effect, part of the capacity of those companies and not firms seeking business for their own account.

Even if we take out the owner-operators, there are still 12,000 or 13,000 TL companies, a huge number compared to any other segment of the for-hire business. As we see in Exhibit 3-2, a very substantial share of the revenue is with small and middle-sized firms. Assuming annual revenue of $125,000 per tractor,[8] a company with 100 tractors has revenue of $12.5 million and is not a big company. But firms with fewer than 100 tractors have around 43 percent of sector revenue. If we go up to 500 tractors, revenue of $62.5 million, we find 68 percent of total TL revenue going to firms with less revenue than that.

[8] This figure is used by Transportation Technical Services in the 2002 edition of the National Motor Carrier Directory to estimate TL revenue. Discussions with TL firms and industry experts on the ICF team confirm that this is an acceptable basis for an approximate estimates.

Exhibit 3-2:
Truckload Revenue by Firm Size

Tractor Size Class	Revenue (millions of $)	Percent
1 – 5	9,768	8.9%
6 – 24	12,369	11.2%
25 – 99	25,597	23.3%
100 – 499	27,250	24.8%
500+	35,059	31.9%
TOTAL	**110,042**	**100.0%**

Sources: These estimates, the methods for developing them, and the underlying data sources are presented in Appendix A.

The truckload business is an example of an industrial sector where something like atomistic competition actually prevails. This fact is reflected in the tight average operating ratio of this segment, 95.0 percent.

A truckload company is analogous to a tramp-steamer company in the ocean-freight business. The trucks do not operate on fixed routes and schedules; they go where the loads are. It is a bit difficult to generalize about operating patterns of TL firms. Some firms will concentrate in a particular region, some in very specific traffic lanes, and some will criss-cross the nation, taking the best loads, in a business sense, as they find them. A TL company's dispatching staff live in a complex world, where they are constantly trying to make optimal decisions as to how to allocate their equipment and drivers to the available loads, bearing in mind a host of cost considerations and, of course, HOS rules.

Regarding the 40,000 owner-operators, it is reasonably clear that companies with five or fewer tractors can support neither a sales force nor a dispatch center. Typically, such companies function in one of two ways. Some of them will get their business from one or two customers with whom they have contracts, or some kind of arrangement, to haul loads among a few points. Others may put their principal reliance on trucking brokers who provide, in effect, their marketing and dispatch functions. As companies increase above the minimal size, there will be at least one person giving most, or all, of his time to sales and dispatch, and then as revenues increase, there will be groups for these functions.

Truckload companies do not have terminals in the same sense as LTL companies. Most TL companies will have a home terminal, but it is principally a site for offices, maintenance facilities, and a place to park tractors and trailers when they are not on the road. Some companies that serve large geographic areas will have multiple bases, but some will not.

Less-than-truckload Companies

As already noted, LTL companies are a sharp contrast with TL firms, both in degree of concentration and in mode of operation. Thirty-five companies receive 85 percent of sector revenue. (See Appendix A.) The seven largest LTL concerns have combined revenue of $13.7 billion, about half the sector total.

While the LTL sector has a much higher degree of concentration than does the truckload business, it is, in total, much smaller than the TL world: total revenue of $27 billion, compared to about $110 billion. There are over almost 500 LTL companies that list themselves as having average hauls of less than 150 miles. We cannot be certain of the nature of all of these concerns, but the likelihood is that they are local-cartage operations. Some of the service they provide would be local LTL movement in the sense that actual origin and destination are within 150 miles of each other. A good part of their service would also be provision of pick-up and delivery service under contract with a larger LTL company that uses a local concern to avoid investing in a terminal in that area.

In order to operate its business, whether regional or national, a LTL firm requires a set of terminals. Each terminal will have a force of pick-up and delivery drivers. Typically, they go out in the morning with loaded trucks, make deliveries, spend the afternoon picking up shipments, and return to the terminal at the end of the day with outbound loads. These shipments are moved across the dock to outbound line-haul trailers that will run overnight to get loads to destination terminals in time for delivery the following morning, when the pick-up and delivery cycle is repeated. Some loads may be going out of a carrier's region; they would be handed over to another LTL firm for onward movement to a destination at one of the other company's terminals That is the general pattern of operation in a regional LTL company.

For the three "national" LTL firms, those that provide long-haul service and have average lengths of haul in excess of 1,000 miles, the operation is somewhat more complicated. These companies will have a set of major hub terminals, each of which has a large number of satellite terminals. Line-haul moves will often be from satellite to hub to hub to satellite. In some circumstances, a trailer may go directly from a satellite to a hub in another region or vice versa. Where the line-haul is more than 500 miles, moves are frequently handled with either teams or relays. (The national companies are Roadway Express, Yellow Freight System, and ABF Freight System.[9])

With due acknowledgement to the complexities in long-haul LTL operation, it is the case that LTL trucking operates in a somewhat scheduled and routinized manner that is utterly different from the opportunistic journeys of a TL company. Many LTL over-the-road drivers make the same run every night, and some of them may never sleep away from home. As will be discussed further in Chapter 5, this makes the analytical approach to the LTL sector completely different from that taken with truckload operations.

Private Carriage

For-hire truckers are in the business of carrying other people's goods. Private carriers are firms that choose to carry their own goods. Generally, private carriers do this because they are very sensitive to requirements for timely and reliable service, either because of their own methods of supply-chain management or those of their customers. It is also the case for some private carriers that having their own drivers handle delivery to customers is part of their customer-relations efforts. Whatever the reason may be, private carriers pay a price for moving their own goods. The alternative in most cases would be for-hire truckload service; private carriage is somewhat

[9] Consolidated Freightways closed down in September 2002; until then, it was one of the largest LTL firms.

more costly than truckload—a premium of a little more than ten percent on a truck-mile basis.[10] Several factors may account for this difference: the high level of service that private carriers provide themselves which would include a higher ratio of empty miles to loaded miles; economies of specialization realized by truckload companies; and generally more expensive pay-and-benefits packages for private drivers. Many private carriers try to offset this cost differential by seeking loads on a for-hire basis for their backhauls that would otherwise be empty.

Information on private carriers is more limited than is the case with for-hire carriage. Private carriers are not treated as trucking companies by many data-gathering efforts; thus, we do not have the sort of data that is available from published sources on at least the larger for-hire companies. Private carriers may range in size from a handful of small trucks used in local delivery to thousands of tractors in long-haul service. We estimate that about 700,000 tractors and drivers are employed in private, long-haul service. Perhaps 100,000 tractors are in short-haul service together with a much larger number of straight trucks. Imputed revenues have been estimated for private carriage: $123 billion in long-haul service and $122 billion in short-haul service.[11]

An important point is that private short-haul operations include a great deal of truck movements that do not involve carriage of goods. These involve trucks that carry people and equipment to places where they are needed to provide services of one kind or another. This includes service trucks belonging to telephone and electric utility companies; trucks of a variety of types of service contractors—plumbers, electricians, roofers, and landscapers; trucks taking crews and equipment to construction sites; dump trucks; and trash trucks; and other vehicles. Otherwise, a great deal of short-haul private carriage is local distribution—movement of snack foods, beverages, fuels, etc. to wholesale or retail points, and retail deliveries to households and offices of many kinds of goods.

It is difficult to generalize about private-carriage patterns of operation. In short-haul service, a driver starts from a store or warehouse and makes a circuit of deliveries in the region, frequently covering the same approximate route every day. In long-haul operations, there can be considerable variety. A firm may ship, for example, from a single national point to a small number of regional distribution centers (DCs) which, in turn, ship to a large number of stores or more DCs. Multiple drops are quite common: a driver leaves a factory or warehouse with a full trailer and makes several delivery stops before returning home. Some runs of this nature require the driver to spend several days on the road, just as a TL driver would. There will be other private operations in which the drivers never spend a night away from home.

We believe that, generally, private operations are much more of a scheduled and routine nature than is the case with for-hire TL operations. Private carriage has something in common with LTL companies in this regard. And, as with LTL service, private operations can experience extra

[10] Transportation Technical Services, *America's Private Carriers,* 1999, p. 101.

[11] Transportation Technical Services, *The Motor Carrier Industry in Transition* 2001, p. 29. Estimates for 1999 were adjusted to 2000 with general-freight growth factors from the Economic Census.

stresses on their capacity at times due to peak-demand times and also to unforeseen incidents that disrupt normal schedules.[12]

We note that many TL companies are plagued with a very high rate of driver turnover; retention of drivers is a major issue in the TL sector. This is not the case in LTL and private operations. Part of this difference stems from better pay and benefits in these latter sectors; and part of this is because many of these companies either employ union drivers or must compete with union employers to obtain good drivers. But part of it is surely due to the irregular and often-shifting work times of TL operation.[13]

Some firms arrange for their private carriage on a contract basis; they outsource their carriage to a contractor, usually a truckload company that dedicates an agreed number of trucks and drivers to a private carrier's service. Since the equipment and drivers are under the control of the private carrier, such an operation behaves in the same way as any other private carrier.

[12] These observations are based on interviews with private carriers and the experience of the ICF team's industry experts.

[13] These observations are based on interviews with private carriers and the experience of the ICF team's industry experts.

4. DESCRIPTION OF THE HOS OPTIONS AND SCENARIOS CONSIDERED

An enumeration of the provisions of the current HOS rules and options is required in order to understand and model quantitatively the effects of changes in rules. Comparisons are made from a baseline of current rules under full compliance to three other options that are based as closely as possible on suggestions or proposals provided by Parents Against Tired Truckers, American Trucking Associations, and FMCSA. The effects of the proposed options relative to the current condition (given full compliance) are based on the following understanding of the proposed options and current rules. Exhibit 4-1 provides a simplified, tabular version of the narrative description.

4.1 Current HOS Regulations

The daily provisions of the current rules allow operators to be on-duty for a total of 15 cumulative hours and to drive for 10 cumulative hours. (In all cases, driving time is part of on-duty time.) When the limit is met, operators must have eight consecutive hours off-duty. The count of on-duty and driving hours resets after eight consecutive hours off-duty. These daily provisions can be expressed as: Operators can cumulatively drive up to 10 hours and be on-duty up to 15 hours since the end of their last eight-consecutive-hour break. Hours do not expire for the daily provisions after 24 hours.

The multi-day provisions of the current rule limit on-duty time to a maximum of 60 hours over any seven consecutive 24-hour periods or 70 hours over any eight consecutive 24-hour periods.[14] There is no differentiation between on-duty and driving time for the multiple-day provisions. Once a driver reaches the limit, he may not drive until on-duty hours on previous days fall back within the allowable amount. These multi-day provisions could be expressed as "Operators can cumulatively drive or be on-duty up to 60 hours over the last six consecutive 24-hour periods plus the current 24-hour period or 70 hours over the last seven 24-hour periods plus the current 24-hour period.

4.2 Parents Against Tired Truckers Option

The daily provisions under an option reflecting docket comments of PATT limit on-duty time to 12 consecutive hours after the operator begins on-duty status and 10 cumulative hours of driving. Once the limit is met, operators must have 12 consecutive hours of break. After the required break the count of hours resets to zero.

The PATT multi-day rule provisions limit operators to 60 hours on duty over the last 6 consecutive 24-hour periods plus the current 24-hour period and/or 50 hours of driving over the last 6 consecutive 24-hour periods plus the current 24-hour period. Once a driver reaches the limit, he must remain off-duty until on-duty hours on previous days fall back within the allowable amount. These multi-day provisions could be expressed as Operators can cumulatively be on-duty up to 60 hours and/or drive up to 50 hours over the last 6 consecutive 24-hour periods plus the current 24-hour period.

[14] For both provisions, these periods include the current 24-hour period.

4.3 American Trucking Associations (ATA) Option

The daily provisions under an option modeled after statements of preferences by ATA limit operators to 14 cumulative hours on-duty after beginning on-duty status. Driving hours are not considered separately from hours on-duty, and off-duty breaks do not count against the 14-hour limit. These hours are cumulative on-duty hours and do not include any off-duty breaks. Duty hours may be extended up to twice a week for up to 16 hours, if shifts that are shorter by the same number of hours are taken the following days.[15] Once the limit is met, operators are required to have ten consecutive hours of break. Drivers with sleeper berths are allowed to split the ten-hour period into two separate breaks of consecutive hours summing to ten hours.[16] The count of hours resets at the end of the required break.

The ATA multi-day rule provisions limit operators to 70 hours over the last seven 24-hour periods (ending with the last completed 24-hour period) or 140 hours over the last 14 24-hour periods. No more than 84 hours are allowed in one of the seven 24-hour periods. If 84 hours are reached within that period, it must be followed by a 34-hour off-duty period. No more than 56 hours are permitted in the remaining seven 24-hour periods. A 34-hour break is required only if, in the 140 hour averaging option, 84 hours are accumulated in the first seven 24-hour periods. No specific length break is required for the seven-day option; however, once a driver reaches the limit of 70 hours, he must remain off-duty until on-duty hours on previous days fall back within the allowable amount. The count of hours for the seven-day option resets to zero after a (non-mandatory) 34-hour break but does not for the 14-day option.[17] This rule can manifest itself as a regular weekly schedule of 70 hours in six days followed by a 34-hour off-duty period.[18]

4.4 FMCSA Option

The daily provisions of FMCSA's option limit operators to 14 consecutive hours of on-duty time, including up to 11 cumulative hours of driving. The count of on-duty hours is consecutive, meaning that they are inclusive of any off duty breaks that are taken during the 14 hours after beginning of the on-duty shift. The count of hours driving is cumulative and are not inclusive of any off duty breaks. Once the limit is reached, ten consecutive hours of break are required (14 hours after beginning on-duty status following the last ten consecutive hour off-duty period). At the end of the required break, the hours reset to zero. Short-haul operators are allowed to be on duty up to 16 consecutive hours one day during a seven-day work week so long as two such days do not occur consecutively.

[15] Because of its complexity, this aspect of the ATA option could not be modeled fully in the long-haul analysis. In long-haul operations, it was modeled as a 14-hour limit on each day.

[16] There are also a few special exceptions for specific markets such as drivers using natural gas well sleeper units (49 C.F.R. §395.1). Because this provision applies to relatively few drivers, ICF does not account separately for these exceptions.

[17] In the ATA recommendations, the 34-hour break required after accumulating 84 hours in the first seven 24-hour periods does not allow the 56-hour maximum to be exceeded in the second 7 24-hour periods, and it is not possible to exceed the 84 or 56-hour maximums in a seven-day period in which an extra 34-hour break has been taken, given the 14-hour maximum per 24 hours. If the driver is on-duty for just under 84 hours in the first seven 24-hour periods, however, no 34-hour break appears to be required, and the driver can exceed the 56-hour maximum.

[18] Though the 34-hour off-duty period is not required under these circumstances, it could be desirable for carriers that wish to increase the utilization of their drivers and vehicles because it resets the count of hours.

The multi-day provision in the FMCSA proposal option is the same as the current rule except for a reset provision. The FMCSA proposal allows operators to work 60 hours over any seven consecutive 24-hour periods or 70 hours over any eight consecutive 24-hour periods.[19] There is no differentiation between on-duty and driving for the multiple-day provisions for any of the proposals. The FMCSA proposal differs from the current rule in that once the hour limit has been met, a 34-hour break is required. The count of hours resets at the end of the required break, allowing additional hours to be accumulated than under the current rules. These multi-day provisions could be expressed as "Operators can cumulatively drive or be on-duty up to 60 hours over the last six consecutive 24-hour periods plus the current 24-hour period or 70 hours over the last seven 24-hour periods plus the current 24-hour period."

The sleeper berth provisions of the FMCSA option are similar to the current rules. It should be noted that though driving would not be permitted after 14 hours from the start of the tour of duty, some of the time within that period may be in off-duty status (e.g., in rest or meal breaks). Though such "off-duty" time could not be used to extend the 14-hour "workday" (as would be permitted under the ATA option), those hours would not count against the multi-day "on-duty" limitations.

Exhibit 4-1
Proposed Hours of Service Regulations Analyzed

Proposed Option	Maximum Hours On-Duty	Maximum Hours Driving	Off-Duty Break	Count of Hours Resets?
Current HOS Rules Daily Provisions	15 cumulative hours	10 cumulative hours	8 consecutive hours	Yes
Multi-Day Provisions	60 hours over any 7 consecutive 24-hour periods or 70 hours over any 8 consecutive 24-hour periods	No difference in on-duty and driving for multi-day provisions.	Off duty until complied with limit	--
Parents Against Tired Truckers (PATT) Daily Provisions	12 consecutive hours after first beginning on-duty status	10 cumulative hours	12 consecutive hours	Yes
Multi-Day Provisions	60 hours over the last 6 consecutive 24-hour periods plus the current 24-hour period.	50 hours over the last 6 consecutive 24-hour periods plus the current 24-hour period.	Off duty until complied with limit	--
American Trucking Associations (ATA) Daily Provisions	14 cumulative hours after first beginning on-duty status (excluding short breaks), with up to 2 additional hours allowed twice per week if offset by equivalent off-duty time the day following the extended work day.	Not considered separately from hours on-duty	10 consecutive hours off-duty required	Yes
Multi-Day Provisions	70 hours over the last 7 24-hour periods (ending with the last completed 24-hour period), or 140 hours over the last 14 24-hour periods, with no more than 84 hours allowed in one of the 7 24-hour periods, if followed by a 34-hour off-duty period, and	No difference in on-duty and driving for multi-day provisions.	A 34-hour break is required only if, in the 140 hour averaging option, 84 hours are accumulated in the first 7 24-hour periods.	Count of hours resets to zero after a 34-hour off-duty break for the 7-day option but not

[19] For both provisions, these periods include the current 24-hour period.

Proposed Option	Maximum Hours On-Duty	Maximum Hours Driving	Off-Duty Break	Count of Hours Resets?
	no more than 56 hours in the remaining 7 24-hour periods. This rule can manifest itself as a regular weekly schedule of 70 hours in 6 days followed by a 34 hour off-duty period.			for the 14-day option
FMCSA Daily Provisions	14 consecutive hours after beginning on-duty status (including breaks). Short-haul drivers are allowed 16 hours once per work week.	11 cumulative hours	10 consecutive hours. (14 hours after beginning on-duty status following the last 10 consecutive hour off-duty period.)	Yes
Multi-Day Provisions	60 hours over any 7 consecutive 24-hour periods or 70 hours over any eight consecutive 24-hour periods.	No difference between on-duty and driving for multi-day provisions.	34 hours	Yes

5. ANALYSIS OF IMPACTS OF HOS RULES ON MOTOR CARRIER OPERATIONS

5.1 ANALYTICAL APPROACHES

5.1.1 Overview

Our goal is to determine whether, and by how much, a rule change increases or decreases the cost of providing trucking service. The focal point of our inquiry is a rule's effect on the number of drivers and vehicles required to sustain the service the trucking business now provides to its customers. Put another way, the question is: Will a rule change require a trucking company to use more or fewer drivers and vehicles to provide its customers the same service they are getting under the current regime? And how many?

Before proceeding further, we need to recognize an element of over-simplification in the question just posed. In the real world, an individual firm might well not respond to a rule-imposed cost change by continuing to provide the same service to the same customers. This would be particularly true for a truckload company. It is not bound to a set of terminals as is a LTL operation, nor to a set of warehouses and stores as is a private carrier. A TL firm can adjust rapidly to changing circumstances, and would probably do so in the case of a HOS rule change, withdrawing from some markets, entering others, and modifying its service in various ways.

This is likely to be the case, even though all of a firm's competitors would be equally affected by the rule. Each individual firm would react to the changes in its cost structure, while the level of service offered by the TL sector as a whole would change only to the extent that higher or lower trucking prices would shift freight to, or draw it from, intermodal rail service. Nonetheless, the best approach to analyzing some sectors is to model the responses of individual firms to rule changes. Although different firms might choose different responses to a rule change, the relative impacts on each firm's costs should be the same.

In order to choose our analytical approaches we have to consider the characteristics of trucking industry sectors and the general nature of the impact on them of the HOS options under consideration. We have already discussed, in Chapter 3, the diverse elements that make up the trucking industry. We need to return to that point as we consider the specific analytical approaches or mechanisms we will use to determine truckers' responses to the HOS rule options. Exhibit 5-1, on the following page, lays out the principal industry sectors and the chosen methods of analysis. In the following discussion, we address each segment and the associated method.

Exhibit 5-1
Methods of Analysis and Industry Segments

Long-haul and regional	**For-hire**			**Private**
	Truckload (TL)	**Less-than-truckload (LTL)**	**Package Service and Household Goods**	
	Model simulation of a firm's responses	Line-haul operation not significantly restrained by any options. Discussion in text.	Not directly analyzed. Discussion in text. Case of package carriers is similar to LTL case.	Model simulation of a firm's responses
Short-haul and local	All short-haul and local trucking analyzed as a single case, relying on survey data on hours actually worked by all types of drivers in this category.			

5.1.2 Line-haul Less-than-truckload Operations

In the LTL context, "line-haul" refers to moves between terminals, as distinct from pick-up and delivery operations, each of which moves shipments to and from a single terminal. None of the three rule-change options is expected to impose a significant restraint on line-haul operations. There are two reasons for this. One has to do with existing work shifts, the other with loading/unloading work.

The LTL sector is set up to operate in compliance with current rules. Terminals are spaced and movements are planned so that virtually all runs can be made comfortably within the ten-hour driving limit or within the driver's work shift, whichever is shorter. We believe the following five cases account for almost all LTL line-haul operations. (One day, as used here, means a day's trip for a solo driver, the distance that can be covered in ten hours.)

Case 1 Terminals one-half day apart. Driver makes the round trip overnight and rarely, if ever, sleeps away from home.

Case 2 Terminals one day apart. Driver makes the trip overnight, sleeps away the next day, and makes a return trip to his home terminal the following night.

Case 3 Terminals one day apart. Two drivers meet at a mid point, swap trailers, and return to their home terminals. Drivers rarely, if ever, sleep away from home.

Case 4 Terminals more than one day apart. Team drivers or relays are used. They may or may not make a return trip directly back to the home terminal.

Case 5 Terminals less than a day apart. Either team or solo drivers are used to make an overnight circuit of several terminals, returning to home terminal by the next morning.

The first three of these cases entail regularly scheduled runs that would take less than ten hours. The fourth case involves teams or relays. Both the current rule and the options allow each member of the team to drive ten hours a day. Further, there is general agreement within the industry that 20 hours a day is the maximum that a team can do in any event, regardless of the rules. Breaks of one kind or another will require four hours in every 24 hours. Relay points will be spaced to be within ten hours or the driver's work shift, whichever is shorter.

In the fifth case the driver (or team) makes a circuit of terminals. At each terminal he drops a trailer and picks up another one, which he takes to the next terminal, and so on until he completes his run by bringing a trailer back to his home terminal. These runs are not as tightly scheduled as those in the other cases. There may be delays at terminals where an outbound trailer is not ready on time. The general pattern is that the driver has little or no role in loading or unloading; he drops a loaded trailer and picks up a loaded trailer. The requirement for some waiting time, however, means that driving time is well below ten hours. These runs are generally planned to be completed within 12 hours, and it appears to be a rare exception when that time is exceeded. In a variant on this case, the driver pulls the same trailer throughout the run, dropping off and picking up shipments at each terminal. This type of operation (known as "kick and pick") may entail some loading and unloading by the driver, depending on the company.

Except for the circuit-of-terminals case, line-haul drivers with a union company will generally not have work shifts in excess of nine-and-one-half hours. As we just noted, a driver making a circuit of terminals ordinarily does so within 12 hours. Non-union companies do not plan shifts in excess of 12 hours.

It is the case, then, that none of the options would restrain current total on-duty times in LTL line-haul operations; the most restrictive option, PATT, has an on-duty limit of 12 hours. We must note, however, that there must be occasions, albeit rare, on which something goes wrong and a work shift stretches beyond 12 hours. To the extent that such instances occur, PATT would impose some cost that is not captured in this analysis. We feel safe in asserting that cost to be small, but we cannot put a value on it.

While none of the options nominally reduces driving time below ten hours, PATT's on-duty limit of 12 hours would have that effect if waiting/loading/unloading exceeded two hours in an on-duty period. With some exceptions, line-haul drivers are not responsible for loading or unloading the trailers they pull, whether union drivers or not. A non-union company with a 12-hour shift might expect its drivers to complete their shifts by doing dock or warehouse work at the destination terminal. But it is not a case of a driver having to stay on duty until his trailer is unloaded; when the 12 hours are up, the driver is off.

We know of at least one case (so there may be others) in which a non-union LTL company has its line-haul drivers carry out cross-dock movement of loads at destination terminals. In this firm's operation, all drivers return to their home terminals at the end of their shifts. A solo driver makes a maximum run of 250 miles to a destination terminal; loads going beyond that terminal are shifted cross-dock to other trailers going back to other terminals. The cross-dock load shifting is done by the line-haul drivers. But even in this case, the entire run is ordinarily completed comfortably within 12 hours.

Generally, then, it is true that waiting/loading/unloading time is not a significant factor in the working day of a line-haul LTL driver. The PATT option, therefore, would not effectively reduce the allowed ten hours for driving. And, as noted above, line-haul work shifts are such that ordinary practices would not be restrained by PATT's 12-hour on-duty limit. We need to repeat, however, that the 12-hour on-duty time leaves little margin for unanticipated delays and would, necessarily, impose some cost on LTL line-haul operations, a cost we cannot quantify but believe to be small.

LTL drivers ordinarily work five-day weeks; none of the weekly rules in the options would restrain the current pattern of working. But the point just made about out-of-the-ordinary situations needs to be repeated in this context. There could be some cost imposed by the PATT option under unusual circumstances.

One further issue needs to be addressed here. This discussion has focused on whether any of the options imposes a restraint on LTL line-haul operations. We believe that restraint is slight and any negative effect on the sector would be slight. On the other hand, two of the options, ATA and FMCSA would reduce restraint, because they would allow longer driving times. For many LTL companies this would raise the question of whether they would want to adjust the spacing of their terminals to take advantage of longer line-haul moves. Obviously, any adjustment of terminal spacing could entail large capital expenditures. A LTL firm would not make such an investment, however, if it did not expect to get an adequate return on its capital. That being the case, a readjustment of terminal spacing would not occur unless it led to an improvement in efficiency of LTL operations.

5.1.3 Package Service

The biggest part of the package sector is United Parcel Service (UPS), and FedEx is the second biggest. (Note that data on FedEx activity levels, revenue and so forth, generally is not reported as part of trucking-industry data. FedEx considers itself an airline, is a member of the Air Transport Association, and its numbers are usually included in aviation-industry data.) Like LTL companies, only more so, these firms have extensive pick-up and delivery operations and separate operations for moving traffic between terminals. For both firms it is the case that much of their line-haul moves are not on the highways; they go by air or intermodal rail.[20] Nonetheless, both firms move very large volumes of traffic in long-haul trucks. These line-haul moves are similar to union LTL operations in that runs are regularly scheduled and are planned to be completed well under ten hours; and loading, unloading, and waiting times are not an issue. Therefore, we believe that any rule impacts on line-haul package operations would be minimal, and we made no attempt to analyze them.

Local package operations are covered in the analysis of short-haul and local operations.

5.1.4 Household Goods

Household goods (HHG) movements are radically different from other forms of truck operation, because of the very large amounts of time required for loading and unloading. The time required for one loading or unloading can range from four to eight hours. Typical working days are eight to ten hours and typical working weeks are 45 to 50 hours. Operations on this basis would not be affected by any of the options under consideration. We have to note here, as in some other instances, that there may be occasions where unanticipated circumstances cause drivers to have to put in more on-duty time than is ordinary and reductions in total allowed on-duty time might impose some cost in this way. We believe this cost to be small, but we cannot estimate it.

[20] This observation was made by a UPS source in Washington, D.C.

5.1.5 Truckload Operations

Long-haul and regional TL companies would feel the greatest impact from changes in HOS rules. These are essentially unscheduled operations, working in a highly competitive environment, under strong pressure to keep drivers and trucks moving. HOS rules are a major feature in the daily decision-making of these companies as they try to make optimum use of drivers and equipment in the light of each day's new orders. This is a world of complex decision-making. The best course for analyzing these companies' responses to HOS rule changes is to use computer software designed to make these decisions, software in which the HOS rules are among the explicit variables considered in the decision-making process. This analysis is described in Sections 5.3, 5.4, and 5.5.

5.1.6 Private Carriage

Long-haul and regional private carriage is, generally, a more scheduled, more regular, somewhat less stressed operation than TL trucking. But the HOS rules are still a major factor in the planning that private carriers must do in order to optimize their transport and logistics systems. As with TL operations, the decisions of a private carrier can be simulated with computer software, and we found this the best approach to determining impacts on long-haul and regional private carriage. This analysis is also described in Sections 5.3, 5.4, and 5.5.

5.1.7 Local and Short-haul Operations

In general, short-haul trucking work has more in common with "ordinary" work than it does with long-haul trucking. These are five-day-a-week jobs, and much of the time on duty is given to tasks other than driving. Typical work days are eight to ten hours or so and typical weeks are 45 to 55 hours. Many, if not most, of these drivers receive overtime pay past eight hours in a day. The HOS rules, existing or contemplated, are unlikely to have a direct effect on such operations.

Short-haul and local operations may be affected by unforeseen circumstances and some operations definitely experience peak-load pressures, often on a predictable basis, which can cause some drivers to approach, and sometimes reach, the 15-hour on-duty limit. Short-haul trucking includes both private and for-hire goods carriers, and service and utility functions that use trucks but carry no goods. Because of the large variety of short-haul operations, it does not make sense to attempt analysis of particular types or patterns of operation. We have available data (from surveys described in Section 5.2 and in Appendix B) on hours actually worked by short-haul drivers. With these data, we were able to analyze directly the effect of reductions in daily on-duty time. Section 5.2 below describes this analysis.

5.2 Assessment of Short-Haul Operations under Constant Demand

We analyze changes in the labor market for short-haul drivers affected by daily rule provisions by creating a spreadsheet model of variation in short-haul driver daily schedule length to test differences across HOS rule options. The short-haul demand spreadsheet analysis relies primarily on the Virginia Polytech Institute Focus Groups and the Walter Reed Field Study[21] but

[21] Hanowski, Richard, Walter Wierwille, Andrew Garness, Nancy Early, Thomas Dingus. Impact of Local/Short Haul Operations on Driver Fatigue, Task 2: Field Study, Final Report, (2000). (Center for Transportation Research, Virginia Polytechnic Institute and State University), FMCSA report DOT-MC-00-203. Balkin, T., Thome, D., Sing,

also is informed by many discussions with industry representatives with short-haul services.[22] The general approach is to model variation in hours worked among short-haul drivers given current compliance levels. Then we calculate the proportion of person-hours affected if there were full compliance with current rules or the three HOS options.

The Virginia Tech Focus Groups provide useable responses from 81 short-haul drivers, providing almost four times the number of short-haul respondents as the Walter Reed survey, but they were questioned only about *average* amount of time worked daily. A frequency distribution of the average amount of time worked daily was derived from responses by members of the Virginia Tech Focus Groups. Ninety percent of the respondents indicated they worked eight to 12 hours on average, with a few claiming to work up to 15 hours on average.[23] We model the same number of drivers in the spreadsheet as are found in the focus group using the respondents' average time working per day. In order to add variation across days or all drivers, we used the across-day standard deviation of number of hours worked for each short-haul driver in the Walter Reed 2000 field study. From this, we calculated the average standard deviation of workday length across drivers.[24] We use the intra-personal standard deviation from the Walter Reed Field Study of 2.5 hours.[25]

H., Thomas, M., Redmond, D., Wesensten, N., Williams, J., Hall, S., and Belenky, G. (2002). "Effects of Sleep Schedules on Commercial Motor Vehicle Driver Performance," Walter Reed Army Institute of Research, Washington, D.C. 2002.

[22] Preliminary analysis using these modeling techniques in tandem with the VPI Focus Groups data suggest that relatively few person-days for short-haul drivers would be affected by changes in the weekly rules. In addition, available survey data do not differentiate length of work weeks for those with differing average daily work lengths. The largest number of person-days for short-haul drivers affected by the weekly working hour limits would be from the PATT rule. The short-haul drivers most likely to approach the weekly limits in PATT are also those likely to be affected by its 12-hour daily rule provisions. These daily limit provisions should reduce to trivial amounts the extent to which weekly limits would be binding. This would be true because, according to ICF interviews with short-haul trucking industry representatives and survey data, most short-haul driver work schedules include only five days a week. It is unlikely, therefore, that they would work six or seven days a week required to surpass the threshold of 60 hours over six or seven days given the 12-hour daily limit found in the PATT proposal. Similarly, the FMCSA rule option would limit daily working hours to 14 hours a day, or 60 hours per five-day week. Therefore, the probability of short-haul drivers who are not affected by the daily limits but are affected by the weekly limits likely would be negligible. Therefore, we have not modeled cost of weekly rules for short-haul drivers.

[23] When a respondent provided a range of hours worked, rather than a single number, we use the mid-point from that range. The outcome of the modeling of hours per day led to ranges of hours worked that matched well with the range of hours provided by these respondents. Because the drivers tended to use integers in their responses, we calculated these averages as integers only. There were only 23 short-haul participants in the Walter Reed study. Their average hours worked on days on which they worked at least two hours was probably somewhat lower than that for the VT Tech focus group at 8.3 hours on average, with a minimum of 5.5 hours on average and a maximum of 13 hours per day. Most short-haul drivers in the Walter Reed Field Study worked between six and nine hours per day on average, excluding days in which they indicated they worked fewer than two hours.

[24] That is, we calculate the standard deviation by person across days rather than pooling all person days. We excluded days with no work or those with fewer than two hours of work.

[25] The Walter Reed Field Study drivers exhibit an average intra-personal standard deviation of 2.5 which is larger than the overall standard deviation of 1.4 hours daily from drivers in Table 4 of the Virginia Tech Focus Group study (p. 77). Using 1.4 instead of 2.5 would result in about half as many modeled person days surpassing the 12-hour (PATT proposal) threshold, and less than a third as many days surpassing the threshold for the other proposals.

We then model the number of hours worked per day over a 25 workday period for each focus group respondent. We did so by generating normally distributed random numbers using the mean number of hours worked for each of the 81 focus group respondents and the standard deviation across individuals of 1.9 hours from the Walter Reed field study. This results in 2,268 person days of work and about 23,300 person-hours worked for the modeled short-haul drivers. We repeated this process four times in order to average the results found using four different sets of random numbers.

We calculate the percentage of modeled short-haul driver hours that would exceed the 24-hour thresholds under the different proposed rules. The ATA proposal would limit operators to 14 cumulative daily working hours[26] in general and up to 16 cumulative hours two days a week followed by a day off or a day with 12 cumulative hours.[27] This proposal would require about 0.3 percent of short-haul work hours to be shifted to other drivers. These hours are spread slightly more broadly, affecting about 2.7 percent of modeled work days, indicating that only a small amount of time is affected for each affected work day.[28] Current HOS rules, allowing 15 cumulative daily working hours, would require about 0.7 percent of short-haul work hours, spread across about 6 percent of working days, to be shifted to other drivers.

The FMCSA proposed rule would limit operators to 14 consecutive working hours daily[29] with up to 16 consecutive hours allowed one day per week for short-haul operators. It affects a somewhat larger percentage of modeled short-haul operators, requiring 1.4 percent of modeled short-haul work hours, spread across about 5 percent of working days, to be shifted to other drivers. The PATT proposal that limits operators to 12 consecutive working hours daily affects the largest number of short-haul operations, requiring 8.4 percent of modeled short-haul work hours, spread across 40 percent of working days, to be shifted to other drivers.[30]

About half of the short-haul driver days limited by these proposals would have to shift no more than 1.5 hours to come into compliance. The proportion of modeled work days affected suggests that a systematic approach to compensating for the proposal thresholds might be required by fleet managers depending on the distribution of days for which threshold overruns would be expected. If the majority of these days occur during predictable periods or days of the week, companies might be able to hire part time drivers just for those periods or days of the week or shift beginning and ending of day duties normally assigned to drivers instead to non-driver employees. To be conservative (i.e., to avoid understanding the impacts of restrictive rules), we do not make this assumption. Instead, we use to total number of hours in excess of the limits as the basis for estimating the total demand for new drivers.

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[26] We model 14 cumulative working hours as a limit of 16 consecutive hours to account for break and meal times for longer days.

[27] This slight simplification of modeling 12 hours in the subsequent day was equivalent in the modeled data sets to reducing the number of hours worked equivalently in the subsequent day.

[28] For almost a third of these modeled days, drivers exceed working time limits by no more than a half hour.

[29] Because FMCSA limits are based on 14 consecutive, rather than cumulative, hours, we model this as a limit of 13 hours for short-haul drivers to accommodate an hour worth of break time for resting, eating, and other activities.

[30] Twenty-two percent of the modeled work days in FMCSA and 15 percent of those in PATT would require no more than a half hour to be shifted to other workers.

5.3 SCENARIOS FOR LONG-HAUL ANALYSES

5.3.1 For-hire Truckload

Three basic scenarios were run with different lengths of haul:

short-regional	minimum run: 120 miles, maximum run: 350 miles, average: 190 miles
long-regional	minimum run: 150 miles, no maximum, average: 430 miles
long-haul	minimum run: 150 miles, no maximum, average: 700 miles

We imposed minimum and maximum runs for the short-regional case. No maximum was imposed on the model for the long-regional and long-haul scenarios. We specified a minimum for these scenarios, and the difference in lengths of haul came from setting the long-regional and long-haul scenarios in different territories. The short and long-regional scenarios were set in the same territory. This region is roughly the northeastern quadrant of the United States, starting with Illinois on the western end and extending to the East Coast through Indiana, Ohio, Pennsylvania, New Jersey and Delaware, plus New York and all of New England. The home terminal is in Columbus, Ohio. Columbus was chosen because it is in a significant manufacturing area providing a good source of outbound loads. The long-haul scenario includes part of the Midwest—Illinois, Indiana, and Ohio—and all the states west of the Mississippi. The home terminal is in Fort Smith, Arkansas.

Orders are generated on the basis of data in FHWA's Freight Analysis Framework (FAF). These data, supplied to FHWA by Reebie Associates, include truck flows among all the counties in the contiguous U.S. We developed order sets, samples of the FAF in effect, to exercise the model; using all the FAF data would have overwhelmed the model. The order sets were built so that the relative volumes of traffic between O-D pairs were the same in our order set as in the FAF data. If, for example, a given county pair had 0.05 percent of the traffic in the FAF data, it had 0.05 percent of the shipments in our order sets. Each order specifies an origin and destination and a day for pick-up and a day for delivery. If the distance is under 500 miles, delivery is the next day; if over 500 miles, it is the second day. Pick-ups are distributed over the days of the week according to data supplied to us by Reebie Associates based on the actual experience of a large TL carrier and Reebie's general knowledge of the behavior of similar firms.

A critical assumption for the analysis has to do with waiting/loading/unloading times. (For simplicity's sake, we refer to the sum of these times as "loading time"). We used the results of a University of Michigan Trucking Industry Program (UMTIP) survey of drivers at truck stops to develop this estimate. The survey showed an average of six hours per trip for loading time. Most of the reported trips had less than six hours of loading time, but the average was pulled up by a large cluster of trips at the high end of the range. We chose to use the six-hour assumption as the basis for our analysis, because we wished to avoid understating the cost impacts of reducing total on-duty hours.

5.3.2 Private Carriage

Selection of private-carriage scenarios posed some problems. One can postulate a set of basic patterns for private-carriage operations, but there is no empirical basis for allocating shares of private-carriage activity among various patterns. Nor is it possible to specify a set of patterns and assert that they account for all, or almost all, of private movement.

We dealt with this issue by selecting two private scenarios for analysis. We refer to one as the "national one-to-few" case and the other as the "regional one-to-many." These are not necessarily to be thought of as two different companies; they could well be different operations under the same corporate roof. The real point is that our goal is not to simulate companies, as such, but to simulate operations. The one-to-few case could be a manufacturer shipping from one factory to a few regional-hub distribution centers (DCs) from which large numbers of stores or other DCs are served. The regional-hub DCs might be owned by the manufacturer or by its customers. The one-to-many case may be thought of as one of those regional DCs, shipping on to stores and/or lower-tier DCs as the case may be.

5.3.3 National One-to-few Case

We selected Columbus, Ohio, as a likely site for a major manufacturing facility. We postulated shipment to five regional DCs covering the nation. We referred to Chicago Consulting's list of best warehouse sites (Chicago Consulting is a real-estate consulting firm that specializes in commercial property). For serving the nation from five locations, these are: Madison, New Jersey; Macon, Georgia; Palmdale, California; Dallas; and Chicago. Because of the distance, we assumed rail intermodal shipment to Palmdale. We assumed that the DCs were not owned by the shipper, which means higher unloading times. We assumed one-half hour at origin and two hours at destination. Based on interviews with selected private carriers, the two-hour unloading time is somewhat high, but we chose to err on the side of over-estimating, rather than under-estimating, costs of reducing on-duty time.

We specified ten shipments per day, six days a week, to each DC. We did not presuppose the size of the fleet but chose fleet size according to the requirements found by the Dispatch software. That is, we offered some number of drivers and tractors as a starting point. If the simulation showed many loads not delivered, we increased the fleet size; if it left a non-trivial number of drivers and tractors idle, we decreased fleet size.

For all the options but PATT, a fleet of 100 tractors was satisfactory, although there was variation in the intensity of use—the amount of time the average driver actually had to work to deliver the same number of loads varied significantly among options. The PATT option required 125 tractors; under that rule 100 drivers simply could not make the required deliveries. The base for our measure of comparative productivity is this variation in amount of driver time required to deliver the set number of loads. This amount of time is used to scale the number of loads a driver could deliver in a fully employed week under each option.

5.3.4 Regional One-to-many Case

We chose a region within a 500-mile radius from Macon. We ranked counties in that region by population and selected the 30 highest counties on that list. Where populous counties were clustered together in a metropolitan area, we considered that area to be a single destination. Otherwise, destinations were single counties. In this manner, we identified 20 destination points within 500 miles of Macon. We assumed six shipments per day to each destination, six days per week. We assumed three shipments on a trailer; that is, each driver made three drops on a route before returning home. Again, we assumed customer-owned destinations—one-half hour to load, two hours per destination to unload.

We can say that these scenarios are roughly representative of a large amount of private movement, but we cannot claim that they represent all, or even most, of private-carriage activity. But we do note that private carriage (long-haul and regional) may accurately be viewed as a special case of truckload operation. The difference is that private operations are generally more regularized than for-hire operation and perhaps less stressed. Many, if not most, private carriers will not be operating right against the limits of the current rules. Therefore, it is expected that the cost impact of a more restrictive rule on private operations will be less than the impact on TL companies. Put another way, we believe our scenario choices for private carriage will not lead to an understatement of cost impact on private carriers.

5.4 TREATMENT OF HOS RULE OPTIONS FOR LH

The current HOS rules are in the Dispatch model as explicit variables. With certain exceptions, these variables can be adjusted to reflect the options under study. One issue is that Dispatch cannot be adjusted to include break time during a tour of duty. Short, off-duty breaks are allowed under the current rules and under the ATA option: in both cases, the on-duty hours do not have to be consecutive. Industry sources tell us that current practice is approximately one hour of off-duty break for five hours of driving. Therefore, we added one hour to the maximum on-duty times in the current and ATA cases to reflect the off-duty breaks. Only one hour was added because most of the trips entail less than ten hours of driving.

Also, the software cannot be adjusted to reflect the 34-hour restart provisions in the FMCSA and ATA options. This was dealt with by specifying the multi-day rule as 70 hours in six days in these cases; this is a very close approximation of the average hours actually allowed by the restart provisions. Finally, the model cannot be adjusted to reflect the two 16-hour days in the ATA option for long-haul operators. There was no way this feature of the ATA rule could be modeled with the software.[31] Therefore, this provision was not included in this analysis of LH operations.

5.5 RESULTS FOR LH DISPATCH SIMULATIONS

The following table summarizes the results of the dispatch simulations. The numbers in the cells in the table are index measures that reflect relative productivity of drivers under the different rule-change options. The indices are different for the for-hire and private cases. In the for-hire case, the index reflects both number of loads moved and length of haul. Changing HOS rules affects both the number of loads carried and the distances covered by a for-hire, truckload company. If such a company can make longer hauls with a given set of resources, it is likely that it will; longer moves for the same tonnage mean more revenue. In the real world, a company might use fewer resources to carry the same number of loads the same distance in response to less restrictive HOS rules. Either response would reflect the same productivity gain. But our

[31] It was, in contrast, possible to model the two extended days for short-haul drivers in the ATA option as well as one day of different length for short-haul drivers in the FMCSA option. The reason for this is that the short-haul benefits were not modeled using the Dispatch model but, instead, were modeled with a separate spreadsheet analysis.

simulation analyses of for-hire operations use a fixed level of resources, so we see the output vary, up or down, according to the different rule-change options.

The for-hire index is a composite, weighted one-third according to loads moved per vehicle and two-thirds according to distance moved per vehicle. Productivity measures based on delivered orders per driver per week and miles per driver per week can differ somewhat if the length of haul differs under different options. After reviewing the factors that would cause the length of haul to vary, and the relative contributions of driving to non-driving activities to producing value for shippers, we developed a composite measure of productivity that weights miles per driver per week twice as heavily as orders per driver per week. This weighting scheme, which was not intended to be precise, was based roughly on the ratio of driving time to non-driving time for a long-haul truckload shipment. The rationale behind this weighting scheme is discussed in more detail in section 1 of Appendix C.

As discussed above, in the private case we keep the output fixed and observe variation in the level of resources used to produce that output. Most of that variation takes the form of more or less intensive use of the same set of tractors and drivers. The index reflects the number of loads a driver could deliver in a standardized, fully employed week.

Exhibit 5-2
Results of Dispatch Analysis: Relative Driver Productivity

For-hire scenarios	Current rule—full compliance	Current rule—status quo	PATT	ATA	FMCSA
Short regional	100	112	86	117	109
Long regional	100	115	87	120	112
Long-haul	100	115	87	123	114
Private scenarios					
Regional one-to many	100	105	92	109	109
National one-to-few	100	110	90	116	115

These changes in driver productivity are the basis for the cost estimates used in the benefit-cost calculations. Estimates of total vehicle miles of travel for truckload and private carriers and numbers of drivers, presented elsewhere, are used to convert these productivity changes into costs (or benefits) of rule changes. It would be incorrect, however, to use these index numbers directly for that purpose. Not all companies have operations that are always pressing against HOS limits; many do not. We know this from anecdotal evidence and from the findings from the UMTIP driver survey of hours actually worked. The calculations done on the basis of those findings are discussed in Section 2 of Appendix C. We can note here, however, that the impacts on for-hire TL were scaled back to 46 percent of the result from direct application of these indices and to 35 percent in the case of private carriage. The difference in these percentages simply reflects the fact that TL operations are more likely to be pushing against the HOS rules than are private operations.

5.5.1 Other Observations on the Results

Except for the PATT option in the for-hire cases, rule changes have greater impact, positive or negative, as length of haul increases. This is, of course, what one would expect. Both the ATA and FMCSA options increase the allowable driving times. Further, the effect of these increases goes up considerably when a trip is two or more days. When loading and unloading are not in the same work shift, the impact of the on-duty time required for this work is diminished, as more of the on-duty time can be used for driving.

It is important to note the effect of loading times on the impacts of the rule changes. Any reduction in loading times reduces rule impacts because more on-duty time becomes available for driving. For example, if loading and unloading are in a single work shift and require a total of six hours, eight hours are left for driving under the ATA option, only seven hours under the FMCSA option because a one-hour break during driving would be charged to on-duty time. Under the same assumptions, the PATT option would leave only five hours for driving. Excessive waiting, loading, and unloading times are generally thought to be a source of considerable inefficiency in long-haul trucking; and this analysis underscores that point.

6. ASSESSMENT OF COSTS OF CHANGES IN OPERATIONS

This chapter presents analyses of the inputs to motor carriers that are important in estimating the cost implications of the changes in operations described in the preceding chapter. Employment costs are considered first, followed by discussions of the costs of tractors and support services.

6.1 ASSESSMENT OF LABOR COST CHANGES

This section discusses the issues related to the truck driver labor supply and the methodology used for the labor cost changes analyzed under the various HOS options. HOS options are expected to result in changes in labor productivity for truck drivers, leading to changes in driver labor demand. The analysis uses the changes in labor productivity obtained from simulations of trucking routes for the various options and translates them to dollar impacts based on the labor supply relationships for truck drivers.

Issues related to the truck driver wage equation, as a function of job and employee characteristics are discussed first, followed by a discussion of the labor supply elasticity for truck drivers. Components of the indirect labor costs that are associated with driver wage costs are also analyzed to complete the discussion on various aspects of the labor cost changes for the different HOS options.

6.2 ASSESSMENT OF WAGES AS A FUNCTION OF JOB ATTRIBUTES

To analyze the labor costs of the different options, we look at the relationship between hours worked and wages earned for truck drivers. The issue of individual driver wages is important because it is one dimension of the cost of the HOS regulations. As hours of work are shifted from drivers who currently work very long hours to newly hired drivers, the cost implications for carriers depends on the employment costs per additional hour of work by existing drivers relative to the costs for new hires.

6.2.1 Previous Studies

Previous studies on truck driver wages by Rose (1987), Hirsch (1993) and Belzer (1995) have shown some evidence of union wage premium for this sector. One of the effects of the deregulation of the trucking industry beginning in the late 1970s and the subsequent restructuring was to reduce the union wage premium. Belzer finds that to be true for the TL segment but not so much for the LTL segment[32]. Rose also analyzes the same issue and finds that deregulation led to some erosion of union's bargaining power[33]. These studies also find other job attributes and demographic characteristics can be used to explain differences in the wages earned by drivers.

[32] See Michael Belzer. "Collective Bargaining after Deregulation: Do the Teamsters Still Count?" Industrial & Labor Relations Review, 48(4), 1995, 636-655.

[33] See Nancy Rose. "Labor Rent Sharing and Regulation: Evidence from the Trucking Industry". Journal of Political Economy, 95. 1987.

Based on the evidence in the literature, we model truck driver wages as a function of various job attributes and other worker characteristics for the non-union segment of the trucking industry. We focus on non-union drivers in part because we have found that the rules will have a greater effect on the TL segment of the industry, which does not have a strong union presence. In addition, it should be easier to determine the underlying willingness of drivers to work additional hours at various rates of pay, because the effects of union contracts that specify the relationship of pay to hours of work will be absent.

6.2.2 Data and Methodology

The primary data source for the analyses carried out in the following section is the Current Population Survey (CPS) data from Bureau of Labor Statistics (BLS). CPS is a household based survey conducted by BLS every month. We analyze yearly CPS data compiled by the National Bureau of Economic Research (NBER) that give earnings and hours worked for a randomly chosen sample. We combine annual data from 1995 to 2000 and model the wage equation for non-union truck drivers only.

We estimate the wage equation for truck drivers based on their demographic information and job characteristics. We hypothesize that the wage earned by truck drivers depends on their hours worked[34], along with their occupational experience[35], and dummy variables to capture whether they are high school graduates, married, sex, race, whether they are in the for-hire industry, as well as dummies to control for year and regional effects. The details of all the variables used in the regression, including descriptive statistics and the estimated coefficients are presented in Exhibit 6-1.

Exhibit 6-1
Regression Results and Descriptive Statistics for Truck Driver Wage Relationship – 1995-2000

Variable	Definition	Coefficient	Mean	S.D.	Min	Max
Natural Log Hours Worked	ln(Hours Worked)	4.12	3.78	0.149	2.4	4.09
		(5.68)				
Natural Log Hours Worked Squared	[ln(Hours Worked)]^2	-0.398	14.32	1.14	5.74	16.76
		(-4.2)				
High School Diploma Earned	0=No; 1=Yes	0.122	0.784	0.412	0	1
		(13.01)				
Occupational Experience	Age-Years of Ed.-6	0.023	21.28	11.93	1	71
		(20.5)				
Occupational Experience Squared	(Age-Years of Ed.-6)^2	-0.0004	595.1	591.24	1	5041
		(-17.97)				
Married	0=No; 1=Yes	0.076	0.634	0.482	0	1

[34] By including an additional variable based on the square of the number of hours worked, we were able to capture a nonlinear effect of hours on wages. The implication of that is explained in detail below.

[35] Ideally, it would be interesting to look at the effect of driving experience on wages separately, but our data does not allow us to separate the two.

Variable	Definition	Coefficient	Mean	S.D.	Min	Max
		(9.115)				
Gender	0=Female; 1=Male	0.186	0.962	0.191	0	1
		(9.46)				
Race (White or Non-White)	0=White; 1=Non-White	-0.027	0.14	0.347	0	1
		(-2.414)				
For Hire Trucker (Whether Driver Works for the ForHire Industry)	0=No; 1=Yes	0.115	0.36	0.48	0	1
		(14.34)				
Constant	---	-0.393	---	---	---	---
		(-0.28)				

Notes: t-statistics in parentheses
Number of observations = 11,017
Regression model includes region and year control dummies
Data source – Current Population Survey.

6.2.3 Results

All the variables of interest have the expected signs and are statistically significant (except for some of the region and year control dummies)[36]. Of particular importance are the coefficients associated with the two hours worked variables and the distribution of wages implied.

Exhibit 6-2 presents predicted wages for different levels of weekly hours worked for our sample on non-union truck drivers only. Based on the total wage relationship, the model predicts that the average 50 hour/week driver earns $28,307, a 60 hour/week driver makes $33,588 and a 70 hour/week driver makes $38,022 annually.

Exhibit 6-2
Predicted Annual Wages for Different Hours/Week

Hours/week	Predicted Annual Wage
40	$ 22,149
45	$ 25,336
50	$ 28,307
55	$ 31,058
60	$ 33,588
65	$ 35,907
70	$ 38,022
75	$ 39,947
80	$ 41,692

Source: ICF analysis of CPS data

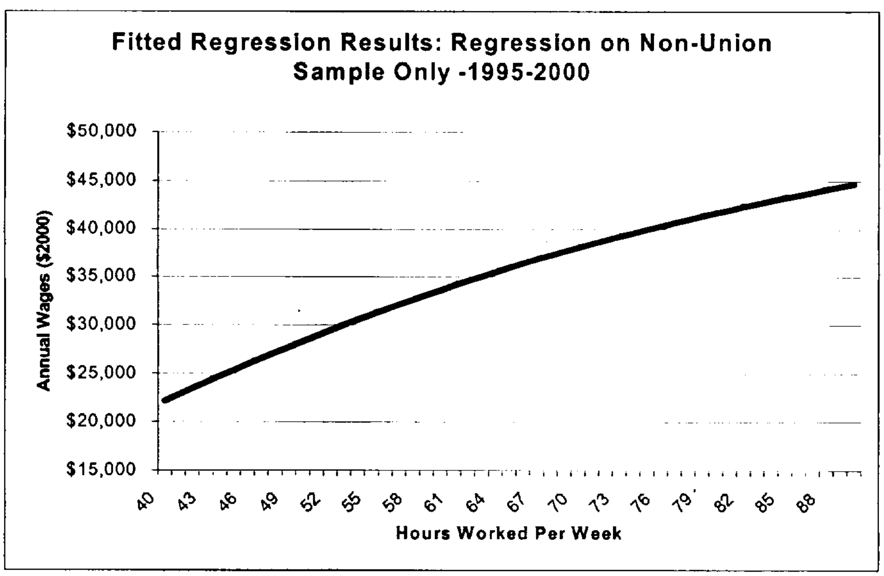
[36] The R-squared of the model is low (27 percent) but consistent with the evidence in the literature - see for e.g., Rose (1987), Hirsch (1988).

These numbers are lower than those obtained by FMCSA in the preliminary RIA.[37] One reason is that we restrict our sample to non-union drivers because we expect them to be the ones that are most affected by the proposed rules. Labor costs are therefore calculated based on non-union wage relationships only. As discussed above, there is evidence of a union premium in truck driver wages, and using a sample of non-union drivers only is expected to give estimates that are lower than those obtained from a full sample of union and non-union drivers. Also, we look at real wages for drivers (in 2000 dollars) for a combined time period from 1995 to 2000. Previous work by FMCSA looked at driver wages for 1997 only.

We believe that our measure of wage costs based on the non-unionized wages gives an accurate picture as there is very little, if any, union presence in the TL sector. Hence we do not expect these HOS options to have any impact on union wage contracts, at least in the TL sector. Also, we expect very little impact of the proposed changes on the LTL sector, which is predominantly unionized with some non-union truck drivers. As discussed in Chapter 3, these LTL drivers operate specific routes every day, and most of them never have to sleep away from home. Hence we believe that the wage costs based on non-union drivers only gives the most accurate measure possible of the labor costs associated with the proposed HOS rules.

Exhibits 6-3 and 6-4 show the implied relationship for the total annual wages (Exhibit 6-3) and the average and marginal wages (Exhibit 6-4), as a function of the hours worked.

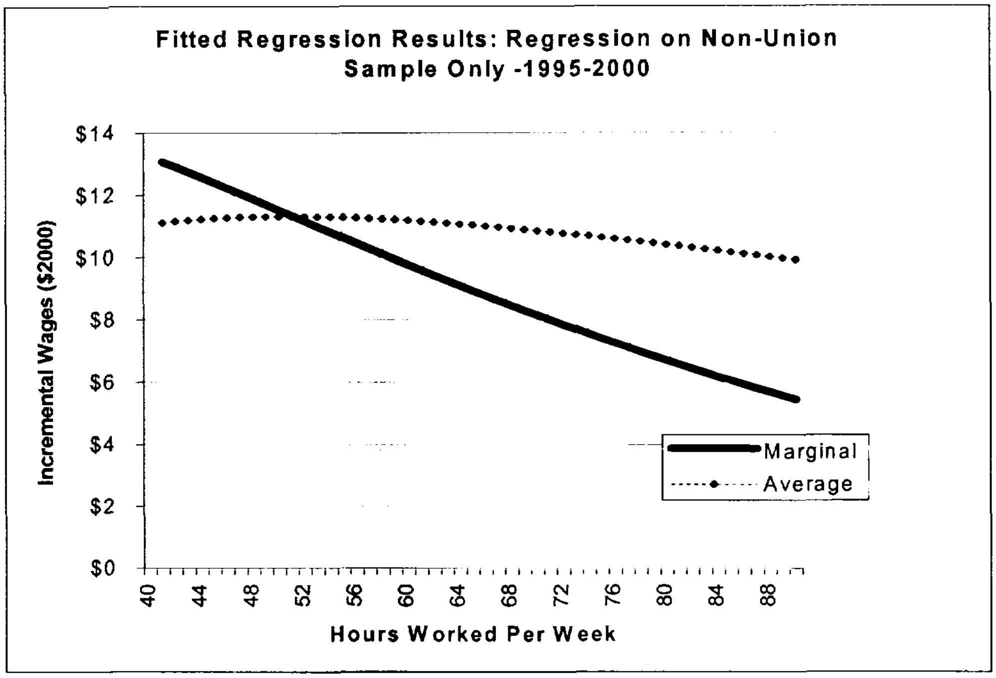
Exhibit 6-3
Total Wage Curve for Non-union Drivers



Source: Regression analysis of CPS data.

[37] The preliminary RIA showed a 60-hour/week driver making $35,737, while a 70 hour/week driver making $38,959 annually. Data from March 1998 CPS was used to come up with these estimates.

Exhibit 6-4
Marginal and Average Wage Curves for Non-union Drivers



Source: Regression analysis of CPS data.

The results indicate that the total annual wages for drivers is an increasing function of hours worked and that it increases at a decreasing rate. This implies that the marginal cost to the firm of an additional hour of driver labor diminishes constantly as the hours of work increases. The specific shape of the total wage curve also ensures that the average wage curve is below the marginal wage for a significant part of the distribution. These relationships are depicted in Figure 6-4.

The downward slope of the marginal cost curve implies that as we curtail the number of hours worked by drivers under different options, the cost savings to companies from cutting down hours of service from drivers is less than the increase in cost due to the hiring of new drivers. Another implication of the slope of the marginal wage curve is that every hour of driver's labor does not cost the same for the trucking company. This is because of the "non-standard" labor-leisure choice faced by truck drivers. While they are on the road, they are willing to work an extra hour for a lower marginal wage (and cost to the firm), to maximize their earnings potential, in part because the value of leisure time out on the road is low. As drivers work more and more hours, the shape of the marginal wage curve implies that the cost to the firm for the extra hours declines gradually.

Another implication of the nature of the driver wage distribution is that the cost changes of the different HOS options modeled are not proportional across the options to the changes in their driver labor demand. Since drivers are allowed to drive/work different hours under the different options, the shape of their marginal wage curve implies that the dollar impacts differ based on the part of the distribution that is affected. Changes in HOS options lead to two kinds of dollar impacts – one related to the avoided labor costs associated with bringing everybody to the limit imposed by the HOS option, and the other related to the new labor costs that have to be paid for hiring new drivers. Since different HOS options affect different parts of the distribution of driver population, these two-dollar values will not necessarily be proportional across all the options.

To illustrate this point further, consider the labor impacts under the PATT and ATA options. PATT is the most restrictive in terms of the number of hours drivers are allowed to drive whereas the ATA option gives drivers more driving hours in a week. Calculating the incremental labor costs of these two options from the baseline[38] imply that the avoided labor costs and the new labor costs do not come from the same parts of the driver distribution for these two options. Consequently, the net effect of these two cost components is not necessarily proportional for the two.

6.3 Assessment of Supply of Drivers

Another aspect of the labor costs of the different HOS options is related to the issue of the labor supply curve in the market for truck drivers. The shape of the labor supply curve determines the impact that changes in labor demand would have on the wage rates for truck drivers, and this is expressed as the elasticity of labor supply.

There is evidence in the literature to suggest that trucking is a very competitive industry with relatively free entry and exit. This is because trucking is considered a low-skill job with relatively low fixed costs. There is evidence that the market labor supply curve is quite elastic. This means, among other things, that a small change in labor demand, as is expected from the HOS options under review, will not lead to any substantial changes in wage rates.

6.3.1 Previous Studies

Rose (1987) contends that the truck driver labor supply curve, especially for the non-union TL sector should be highly elastic. This is because "truck driving is a low-skill occupation with considerable turnover." She also discusses the fact that there is a large pool of drivers outside of the regulated interstate trucking industry who perform the same type of job – owner-operators, private carriage drivers and delivery drivers. She argues thus that the labor supply curve should be highly elastic for this occupation as a whole. Hirsch (1988) also makes the same argument that truck driver labor supply is likely to be highly elastic, given the fact that it is considered a low-skilled job. Engel[39] (1998) argues that the high turnover rate in trucking, especially in the TL sector, indicates that this occupation has a highly elastic labor supply curve and provides an easy entry to new truck drivers. The author further argues that these high rates of turnover also indicate that trucking is a job that is difficult to perform over extended periods. There is evidence in the literature that the trucking industry, especially the TL sector, suffers from significant driver shortage. The details about how this can potentially impact the issue of market labor supply is discussed below.

[38] For purposes of this analysis, we assume a 100 percent compliance with the current rules as the baseline. We also, however, look at the cost implications from a base line consistent with the current state of the world – we call this the "Status Quo". The details of the cost implications are provided in Chapter 9.

[39] Cynthia Engel. "Competition Drives the Trucking Industry". Monthly Labor Review, April 1998.

Other studies that looked at the issue of labor supply elasticity in general (not for trucking only) have come up with estimates ranging between 2 and 5. (See for e.g., Lettau (1994), Eberts and Stone (1992)). These studies introduce a spatial dimension to the analysis by looking at local labor markets and therefore are not directly comparable to the analysis here. Nevertheless, these estimates provide a "benchmark" for labor supply elasticity values. Lettau[40], for example, argues that empirical studies that look at local area labor demand-labor supply relationships, find that "an area's elasticity of labor supply is between 2.0 and 5.0." Eberts and Stone[41] use a recursive model to identify the labor supply and demand relationships in local labor markets using CPS data. They find a labor supply elasticity of 4.9 using a five-period lag structure.

6.3.2 Evidence from Trucking Industry Data

Analysis of historical employment data on truck drivers confirms the view held by experts on this industry that the market labor supply for truck drivers is relatively elastic. Exhibit 6-5 shows the pattern of employment and annual earnings of truck drivers in the economy from 1983 to 2000, based on CPS data. Although driver employment has grown close to a million from 1983 to 2000 (a growth rate of about 40 percent), growth in real wages for drivers has not been nearly that dramatic. In fact, real wage, in 2000 dollars, have grown less than one-half of a percent during the same period.

Exhibit 6-5
Economy-Wide Truck Driver Employment and Real Wage Levels

Year	Employment	Real Wage (2000$)
1983	2,195,000	30,642
1984	2,373,000	30,878
1985	2,414,000	30,687
1986	2,452,000	30,813
1987	2,543,000	30,810
1988	2,608,000	31,190
1989	2,616,000	31,037
1990	2,627,000	30,866
1991	2,684,000	30,463
1992	2,712,000	28,709
1993	2,804,000	28,943
1994	2,815,000	29,846
1995	2,861,000	29,549
1996	3,019,000	29,831
1997	3,075,000	30,014
1998	3,012,000	31,236
1999	3,116,000	31,083
2000	3,088,000	30,759

Source: ICF analysis of Current Population Survey data.

[40] Michael K. Lettau. "Wage Adjustments in Local Labor Markets: Do the Wage Rates in all Industries Adjust?". Office of Economic Research, Bureau of Labor Statistics. May 1994. Abstract available at: http://www.bls.gov/ore/abstract/ec/ec940070.htm

[41] Randall W. Eberts and Joe A. Stone. "Wage and Employment Adjustment in Local Labor Markets". W.E. Upjohn Institute, 1992.

Thus, as FMCSA notes in the preliminary RIA, historical data suggests that employment growth for this occupation has not been "significantly impeded by wage movements".

The Pool of Available Truck Drivers

As FMCSA notes in the preliminary RIA, the issue about the wage elasticity for new drivers should ideally be considered in the context of potential truck drivers. Since hiring new drivers would mean shifting or attracting workers from other competing sectors to trucking, we analyzed the existing labor pool for blue-collar workers to see where the new drivers could come from. Exhibit 6-6 gives the number of blue-collar workers in some of the industries that could supply additional truck drivers needed to comply with the new rules.

Exhibit 6-6
Employment Levels for Blue-Collar Occupations
(in thousands)

Occupational Categories	2000	1995	1990	1985
Mechanics and repairers, except supervisors	4,652	4,173	4,221	4,209
Construction trades, except supervisors	5,153	4,372	4,545	4,143
Extractive occupations, including oil well drillers, explosive and mining occupations	84	90	111	141
Precision Production occupations, including metalworking, woodworking, food prodn. and textile, apparel and furnishings	1,665	1,686	1,691	1,709
Operators, fabricators, and laborers	18,319	18,068	18,071	16,816
Fabricators, assemblers, and hand working occupations	2,070	2,059	1,978	1,833
Farm occupations, except managerial	847	862	964	1,064
Related agricultural occupations (except Supervisors)	1,094	1,024	1,014	765
Forestry and logging occupations (except Supervisors)	89	116	123	96
Transportation and material moving occupations (except Supervisors and Truck Drivers)	2,382	2,209	2,165	2,057
Handlers, equipment cleaners, helpers, and laborers (except Supervisors)	5,429	4,976	4,973	4,431
Janitors and cleaners	2,233	2,071	2,222	2,049
Public transportation attendants	127	94	100	65
Baggage porters and bellhops	42	43	39	20
Total Other Blue Collar	44,186	41,843	42,217	39,398
Truck Drivers	3,088	2,861	2,627	2,414

Source: Current Population Survey

The data in the above table indicates that truck drivers have formed around 5 to 6 percent of a "loosely-defined" total blue-collar population[42] over the years. Most of the occupations listed above can be considered similar to truck driving in terms of attracting people. This is

[42] Our definition of blue-collar workers is broader than that used by BLS. We define it more broadly than BLS, to show the occupations that can potentially supply new truck drivers, if needed.

one reason to believe that there is a large labor pool of blue-collar workers from which to attract potential new truck drivers as a result of the HOS options. This fact, coupled with the historical trends on wage movements, suggests that changes in labor demand would not lead to substantial wage effects due to the high labor supply elasticity.

Some analysts believe the high turnover rates in this industry are not driven by a shortage of drivers. According to a study done by the Upper Great Plains Transportation Institute (UGPTI)[43] in 1990, and quoted in a report on "What Matters to Drivers"[44] published in 1997, the trucking industry does not suffer from a "shortage of drivers" to hire from. The study claims the fact that this industry has been able to sustain such high driver turnover rates over the years is an indication that the problem is not one of labor shortage, but a lack of human resource strategy to take advantage of the available driver pool.

Also, truck driver population in the U.S. under the current conditions is predominantly middle-aged white males. The average age of drivers in the CPS sample is 39 years (for both males and females), with 96 percent of the population being male. However, according to a study done by The Gallup Organization[45], females, non-whites (or minorities) and those that have less than 15 years of experience most likely see trucking as a good occupational choice. There is a growing segment of the labor force that has remained untapped to increase the pool of drivers. Improving the working conditions of drivers and making their job characteristics consistent with other competing occupations would be one way to attract this previously unused portion of the labor force.

Turnover and its Impact on Driver Labor

Another issue that is related to this and could have a potential impact on labor supply is that of turnover. Evidence suggests that this industry, particularly the TL sector, has been plagued by very high rates of turnover.[46]

The Gallup study argues that between 1994 and 2005, the industry will need to hire an additional 403,000 drivers/year (even before new HOS). Of these, about 320,000 (or 80 percent) would be because of "churning" or internal turnover – drivers leaving one company to go to another, because of their dissatisfaction with the present job and pay. Another 34,000 (or 8 percent) would be needed to account for growth in the industry. And the remaining 48,000 (or 12 percent) would be needed because of attrition, retirement and external turnover.

The study also notes five specific job attributes that can predict overall job satisfaction for truck drivers:[47]

[43] Griffin, G.C. and Rodriguez, J.M. (1990). "The Determinants of Job Satisfaction of Professional Drivers," *Journal of the Transportation Research Forum*, 2, pp. 453-464.

[44] See Penneau, B. and Smits, R. (1997). *What Matters to Drivers*, J. J. Keller & Associates, Inc., December.

[45] See "Empty Seats and Musical Chairs: Critical Success Factors in Truck Driver Retention". Prepared by The Gallup Organization for ATA Foundation. October 1997.

[46] Turnover rates are the highest in the TL sector – close to 100 percent. They also have the worst pay structure – see Belzer (1995).

- Steadiness of work (i.e., consistent driving assignments)
- Genuine care of managers for their drivers
- Pay
- Support from company while on the road, and
- Number of hours of work.

Any improvement in the work schedules of drivers that makes it comparable to other competing occupations could therefore have a positive impact on driver turnover. Another important aspect of this issue is drivers' pay structure. Since pay is also listed as an important reason for the lack of satisfaction, any changes in the rules that results in a reduction in pay for drivers can have the opposite impact on driver turnover. Thus the net effect of better work schedules and lower pay is unknown. However, given the fact that we expect this industry to have a large labor supply elasticity, the wage impacts of a change in driver demand should not be significant. Thus the pay changes resulting from the new rules, whether it is an increase or decrease is not expected to be significant.[48]

Based on the issues discussed above and the evidence from previous literature and data on truck driver labor supply, we assume a labor supply elasticity of 5 to measure the impact on wages as a result of a change in demand for drivers. Note that this number falls between the values of 1.5 and 10 used by FMCSA in the preliminary RIA. An elasticity of 5 is consistent with the view held by industry analysts that trucking is a fairly low-skill, easy entry job. Although there seem to be very limited research on truck driver's market labor supply models that are directly relevant for our purposes, an elasticity measure of 5 does not seem to be out of place. Moreover, given that there is a consensus among researchers that the trucking industry has a very high labor supply elasticity, we do not expect the specific number used for the elasticity measure to have a significant bearing on the cost estimates derived in Chapter 9. To put it in another way, we do not expect the changes in labor demand due to the HOS options to have very large impacts on the wage rates because of this high market labor elasticity, limiting the sensitivity of the cost estimates to the choice of the elasticity number.

Another input used in calculating the labor costs of the HOS options relate to the initial driver population. As given in Exhibit 6-6 above, BLS estimates there were approximately 3 million truck drivers in the U.S. in 2000.[49] As discussed in Chapter 3, we estimate there are 1.5 million drivers each for the long haul/regional and the short haul/local segments.

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[47] See "Empty Seats and Musical Chairs: Critical Success Factors in Truck Driver Retention", Prepared by the Gallup Organization for the ATA Foundation, October 1997, page 4.

[48] The sensitivity of the pay structure to turnover is illustrated by the experience of J.B Hunt, a large TL company. The company increased pay and benefits to reduce turnover (they increased driver pay by around 33 percent in 1997 – to about $50,000/year to several thousand long-haul TL drivers). Early evidence suggests that the pay increase reduced turnover by more than one-half. (see Cynthia Engel. "Competition Drives the Trucking Industry", Monthly Labor Review, April 1998.

[49] The NPRM regulatory evaluation used a much larger number of drivers, approximately 6.4 million divided into 5 categories. The NPRM estimate was based on FMCSA-generated data, specifically the drug and alcohol surveys and MCMIS. Neither of these sources were designed to provide estimates of the number of drivers. As explained in this document, this evaluation uses a combination of a bottom-up and top-down approach to arrive at an estimate of 3 million drivers. The top-down approach is to use data from the Bureau of Labor Statistics Current Population Survey, which shows approximately 3 million drivers in 2000. BLS data are commonly used in academic labor research. The bottom-up approach is explained in Appendix A, which

6.4 INDIRECT LABOR COSTS

Two other types of costs that are related to labor productivity changes are fringe benefits for new drivers and the changes in overhead labor costs due to the changes in non-driver labor that is directly related to the changes in driver labor.

6.4.1 Driver Fringe Benefits

Based on data from ATA's Motor Carrier Reports 2000, we estimate drivers in the for-hire TL sector are paid a fringe rate of 20 percent of their salary. Based on the inputs provided by the National Economic Research Associates (NERA), using data from Bureau of Labor Statistics (BLS) "*Employment Cost Trends*", we estimate that private carrier drivers are paid 43 percent in fringes[50]. However, since the cost calculations in this evaluation are done for the combined driver population of for-hire TL and private carriers, we assume a fringe benefit rate of 31 percent as the weighted average rate dependent on the two fringe rates and the distribution of drivers for the two groups.

6.4.2 Overhead Labor

Based on data from the Blue Book,[51] the number of non-driver employees is estimated to be around 25 percent of the total workforce in TL companies. According to an industry analyst, the non-driver labor categories that are directly proportional to changes in driver population are driver managers, load planners and some maintenance and cleaning staff.[52] In the absence of specific data on what fraction of the 25 percent these categories would make up, we relied on our knowledge about the industry and the estimates provided by our industry analyst, and calculated that these would make up approximately 16 percent (or a little less than a sixth) of the total non-driver labor force in TL companies. Thus, for any change in the driver population, we assume there is a 4 percent change (i.e., 16%*25%) in non-driver wages and this is added to the labor costs due to drivers as an overhead labor cost.

6.5 LABOR COST IMPLICATIONS

Using the methodology discussed above, labor costs of implementing the HOS options are calculated separately for the long haul/regional and short haul/local segments. Using the labor productivity changes for these segments as inputs, we calculate the changes in the driver population that would be needed to maintain the same VMT. Then, using the relationships derived from the labor supply curve for individual truck drivers, as well as for the market labor supply, we calculate the avoided and new labor costs and the overhead labor costs for each HOS option. The following table lists the labor related assumptions and values used to calculate the costs in Chapter 9.

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shows how we derived estimates of drivers by industry sector. This approach assures that the number of drivers is consistent with the number of trucks, trailers, and carriers. Another difference is that this document, unlike the NPRM, does not include bus drivers.

[50] See "A Review of the Federal Motor Carrier Safety Administration's Economic Analysis for its Proposed Hours of Service Standard". National Economic Research Associates. August 2000, page 21.

[51] For a description of the Blue Book data, refer to Chapter 3 "Profile of the Motor Carrier Industry".

[52] ICF conversations with George Edwards.

Exhibit 6-7
Summary of Labor Assumptions

	Long Haul/Regional	Short Haul/Local
Current Driver Population	1,500,000	1,500,000
Labor Supply Elasticity	5	5
Overhead Labor Cost Proportional to Driver Labor	4.0%	4.0%
New Driver Fringe Share	31%	31%

Source: ICF analysis of various data sources and literature.

6.6 ASSESSMENT OF NON-LABOR-RELATED COSTS

A change in the number of drivers required to conduct trucking activity requires a complementary change in the fleet size and supporting infrastructure. ICF identified methods for estimating the cost of new assets (tractors, trailers, and parking spaces), maintenance, and insurance costs based on a review of the literature and relevant databases, as well as on the conclusions of its industry experts. ICF assumed no new docking facilities or change in mileage-based costs occurs since no direct change in the number of deliveries or in Vehicle Miles Traveled (VMT) is assumed, respectively.[53]

6.6.1 Trucking Equipment

The method used to estimate the change in the number of tractors and trailers incorporates two countervailing impacts from the change in labor productivity. The first is the obvious change in the number of trucks associated with the incremental change in the number of drivers. The second has to do with the fact that a change in the number of tractors and trailers, under an assumption of no direct change in overall fleet VMT, changes the life of the entire fleet of tractors and trailers, including the life of newly purchased trucks. For example, consider the case of lower labor productivity requiring more drivers and, hence, tractors and trailers. However, the existing fleet is now driving less to maintain the same VMT, meaning that the average life of each truck is longer. On average, this will translate into lower vehicle replacement based on the change in the number of trucks relative to the initial fleet.

For purposes of illustration, the preceding example will be worked through a representative case in which 10,000 new drivers are hired by trucking companies in response to lower labor productivity, where the initial fleet size is 1,500,000 drivers. Exhibit 6-8 summarizes the key assumptions used in the analysis. ICF assessed and incorporated a number of assumptions made by NERA[54] (2001) in their industry-sponsored review of the Preliminary RIA.

The change in motor vehicle expenditures has two implications for the economy that are estimated for purposes of conducting the regional economic analysis presented in Section 9. First, the direct expenditures on equipment are estimated based on the starting year of the

[53] Mileage-based costs would include direct expenditures by trucking companies on fuel, tires, and portions of maintenance and insurance (see below). Docking facility costs would include an increase in warehouse and docking space to accommodate a change in the number of deliveries to be made.

[54] Mark Berkman, Jesse David, Michael Liu, and Alison Pan (2000). "A Review of the Federal Motor Carrier Safety Administration's Economic Analysis for its Proposed Hours of Service Standard." Prepared for the American Trucking Association by National Economic Research Associates (NERA). August 3.

policy, the anticipated reaction time by trucking firms, and the anticipated life of assets adjusted for the change in fleet size. Second, the assumption is made that firms will not simply bear the swings in capital costs in each year. Instead, firms will finance the costs over the amortization schedule at a reasonable weighted-average cost of capital.

The money to cover these transactions is assumed to come from personal consumption in the regional economic framework. In Year 1 of an amortization schedule, consumers provide the cash to cover the change in purchases of new vehicles, net of the first year's principal and interest payments. In subsequent years, consumers receive the remaining principal and interest payments associated with the original loan in the first year. The principal and interest costs represent an increase in the production costs facing trucking-related sectors in the economy.

Exhibit 6-8
Assumptions Used to Model Motor Vehicle Equipment Costs

Variable	Units	Name	Assumption	Source
Ratio of Tractors to Drivers	Ratio	Ratio_TD	0.75	NERA[55]
Ratio of Trailers to Tractors	Ratio	Ratio_TT	1.00	ICF
Cost of New Tractor	$Nominal	Tractor_Cost	$95,000	ICF/NERA[56]
Cost of New Trailer	$Nominal	Trailer_Cost	$20,000	ICF/NERA
Amortization Period	Years	Truck_Amort	5	ICF
Cost of Capital (% Return on Assets)*	Percent	Truck_Cap	14.00%	ICF
Phase In Period	Years	Truck_Phase	2	ICF
Initial Ratio of Trailers to Trucks	Ratio	Initial_RTT	2.50	NERA[57]
Average Tractor Life	Years	Tractor_Life	7	NERA
Average Trailer Life	Years	Trailer_Life	10	ICF

*Pre-tax revenue requirement based on weighted-average cost of capital assuming a debt-to-equity ratio of 1 (50% debt/50% equity), a pre-tax bond rate of 8%, and a 20% pre-tax equity rate

Returning to the example, the steps involved in estimating the changes in the demand for motor vehicle equipment are as follows (t is used to represent time by year and MM for millions):

- Step 1: Estimate the Number, Timing, and Cost of New Tractors and Trailers
    - New Tractors = Ratio_TD * New Drivers = 0.75 * 10,000 = 7,500
    - New Trailers = Ratio_TT * New Tractors = 1.00 * 7,500 = 7,500

[55] NERA evaluated ratios of trucks to drivers based on estimates of 1.14 from an ATA Driver Comparison Study (August 2000), an ATA survey of members at 1.18, and a study by Belzer, Michael, *Hours of Service Impact Assessment*, University of Michigan Transportation Research Institute, March 5, 1999.

[56] NERA evaluated truck valuations and expected lives based on information from Martin Labbe Associates and an ATA report of costs between $60,000 and $150,000 per truck. ICF revised up to $95,000 per tractor based on discussions with its industry experts.

[57] NERA's estimate based on ATA's *Motor Carrier Annual Report* (1998) reporting 737,339 owned and leased trailers and semi-trailers and 294,658 owned and leased truck-tractors. ICF examined the *2000 TTS National Motor Carrier Directory* database that revealed ratios in the 1.95 to 2.30 range.

- For t = 0 to Truck_Phase, New $Tractors_t$ = New Tractors/Truck_Phase = 7,500/2 = 3,750
- For t = 0 to Truck_Phase, New $Trailers_t$ = New Trailers/Truck_Phase = 7,500/2 = 3,750
- Tractor $Cost_t$ = New $Tractors_t$ * Tractor_Cost = 3,750 * $95,000/1MM = $356.25 MM
- Trailer $Cost_t$ = New $Trailers_t$ * Trailer_Cost = 3,750 * $20,000/1MM = $75.00 MM

- Step 2: Estimate the Change in Asset Life of Tractors and Trailers

  - Adj. Tractor Life = Tractor_Life * [1 + New Tractors / (New Tractors + Initial Tractor Inventory)] = 7 * [1 + 7,500 / (7,500 + 1,500,000)] = 7.034829 Years
  - Initial Trailer Inventory = Initial Tractor Inventory * Initial_RTT = 1,500,000 * 2.5 = 3,750,000
  - Adj. Trailer Life = Trailer_Life * [1 + New Trailers / (New Trailers + Initial Trailer Inventory)] = 10 * [7,500 / (7,500 + 3,750,000)] = 10.01996 Years

- Step 3: Estimate the Replacement Timing and Cost for New Tractors and Trailers

  - Tractor Costt+INT(Adj. Tractor Life) = Tractor Costt = $356.25 MM
  - Trailer Costt+INT(Adj. Tractor Life) = Trailer Costt = $75.00 MM

- Step 4: Estimate the Change in Existing Annual Fleet Replacement

  - Δ Annual Tractor Repl. = Initial Tractor Inventory*[(1/Tractor_Life)-(1/Adj. Tractor Life)] = 1,500,000 * [(1/10)-(1/10.01996)] = -1,061 Tractors/Year
  - Δ Annual Tractor Repl. Cost = Δ Annual Tractor Repl. * Tractor_Cost = -1,061 * $95,000 = -$100.79 MM/Year
  - Δ Annual Trailer Repl. = Initial Trailer Inventory*[(1/Trailer_Life)-(1/Adj. Trailer Life)] = 3,750,000 * [(1/10)-(1/10.01996)] = -747 Trailers/Year
  - Δ Annual Trailer Repl Cost. = Δ Annual Tractor Repl. * Tractor_Cost = -747 * $95,000 = -$14.94 MM/Year

- Step 5: Estimate Capital Payments for Each Year's Change in Investment Over Time

  - For each year, calculate aggregate net change in Capital Cost required across Steps 1 to 4
  - Annuitization Factor = [Truck_Cap] / [1-(1/((1+Truck_Cap)^Truck(Trailer)_Amort))] = 29.128%
  - Capital Payment = Annuitization Factor * Capital Cost (associated with a given year's investment – need to aggregate capital payments

across multiple years' investments according to the amortization life and year)

- Capital Payment$_{t=1}$ = ($326.25 MM + $75.00 MM - $100.79 MM - $14.94 MM)*29.128% = $83.168 MM/Year for 5 Years

6.6.2 Parking Space Construction and Maintenance

A change in the number of tractor-trailer sets will require that additional parking spaces be available at terminals. The construction and maintenance of new parking spaces requires both an up-front capital expenditure in the first year followed by annual maintenance costs in subsequent years. The capital expenditures will be capitalized and amortized as a cost to the trucking sector with financing assumed to be substituted for personal consumption as with equipment expenditures. Unlike trucks, no off-setting change in the life of existing parking spaces occurs, because the life of a parking space is expected to be longer than the 10-year horizon under consideration in this analysis.

The assumptions used in the analysis are documented in Exhibit 6-9. Information on parking space requirements for tractor-trailer sets was taken from NATSO (National Association of Truck Stop Owners) and for auto parking spaces from IPI (International Parking Institute). Time at terminals and auto parking rates were stipulated by ICF industry experts. Maintenance costs for auto spaces were assumed to occur at the same ratio as truck space maintenance to capital cost.

Not all new tractor-trailer sets will be at the terminal at any given point in time, where Terminal_Max summarizes the proportion of additional spaces to sets. In addition to parking spaces for new tractor-trailer sets, additional spaces must be constructed for new drivers to park at truck stops, rest areas, or terminals while en route. The ratio of new drivers parking at work to new tractor-trailer sets is accounted for in variable Terminal_TD. The installation and maintenance costs are estimated based on the following steps, following the example from Section 6.5.1.

Exhibit 6-9
Assumptions Used to Model Parking Space Construction & Maintenance Costs

Variable	Units	Name	Assumption	Source
Ratio of Tractor/Trailers Per Acre	Ratio	TPA_Ratio	18.00	NATSO[58],
Ratio of Tractors to Drivers	Ratio	Ratio_TD	0.75	NERA
Max. # of New Trucks at Terminal	Percent	Terminal_Max	75%	ICF
Capital Cost Per Acre for Trucks	$Nominal	TPA_Cost	$100,000	NATSO
O&M Cost Per Acre for Trucks	$Nominal	TPA_OM	$10,000	NATSO

[58] Costs per space based on Scott Imus, National Association of Truck Stop Owners, http://www.natso.com/for_members/government_downloads/truckparking_solutions2001.doc: Assume 18:1 ratio of tractor/trailer sets per acre, $100K construction costs per acre, and $8,000-$10,000 per year in annualized maintenance costs; translates to $5,555 in capital costs and $555 per year in maintenance costs per tractor/trailer set. These values are consistent with estimates of incremental, rest-area pull-off parking space construction costs of $5,000-$7,000 per space based on information derived from truck stop operators and a national rest area database in U.S. DOT, Federal Highway Administration (1996). "Commercial Driver Rest & Parking Requirements: Making Space for Safety – Final Report." Report No. FHWA-MC-96-0010, May, Table III-2, p. 97.

Variable	Units	Name	Assumption	Source
Drivers Parking at Terminal	Percent	Terminal_TD	75%	ICF
Capital Cost Per Space for Autos	$Nominal	APS_Cost	$1,500	IPI[59]
O&M Cost Per Space for Autos	$Nominal	APS_OM	$150	ICF
Cost of Capital (% Return on Assets)*	Percent	Truck_Cap	14.00%	ICF
Amortization Period	Years	Pkg_Amort	10	ICF
Average Life of Parking Spaces	Years	Pkg_Life	20	ICF

*Pre-tax revenue requirement based on weighted-average cost of capital assuming a debt-to-equity ratio of 1 (50% debt/50% equity), a pre-tax bond rate of 8%, and a 20% pre-tax equity rate

- Step 1: Estimate the Number of Parking Spaces Required
  - New Tractor-Trailer Spaces = New Drivers * Ratio_TD * Terminal_Max = 10,000 * 0.75 * 75% = 5,625
  - New Auto Spaces = New Tractor-Trailer Spaces * Terminal_TD = 5,625 * 75% = 4,219
- Step 2: Estimate the New Tractor-Trailer Set Capital & Maintenance Costs
  - TT Set Pkg. Capital Cost = New Tractor-Trailer Spaces * TPA_Cost / TPA_Ratio = 5,625 * $100,000 / 18 = $31.25 MM in Year 1
  - TT Set Pkg. Maint. Cost = New Tractor-Trailer Spaces * TPA_OM / TPA_Ratio = 5,625 * $10,000 / 18 = $3.125 MM in Years 2+
- Step 3: Estimate the New Auto Parking Capital & Maintenance Costs
  - Auto Pkg. Capital Cost = New Auto Spaces * APS_Cost = 4,219 * $1,500 = $6.328 MM in Year 1
  - Auto Pkg. Maint. Cost = New Auto Spaces * APS_OM = 4,219 * $150 = $0.6328 MM in Years 2+
- Step 4: Estimate Capital Payments
  - Calculate aggregate net change in Capital Cost required across Steps 1 and 2 in Year 1
  - Annuitization Factor = [Truck_Cap] / [1-(1/((1+Truck_Cap)^Truck(Trailer)_Amort))] = 19.171%
  - Capital Payment = Annuitization Factor * Capital
  - Capital Payment$_{t=1}$ = ($31.25 MM + $6.328 MM)*19.171% = $7.204 MM/Year for 10 Years

[59] The International Parking Institute states that, "Surface facilities can be built for $1,500 per space in most cases." http://www.parking.org/main/faq.htm; http://wwww.fsfarchitects.com/ExtGuide.htm estimates the ratio of spaces per acre at 80:1 to 100:1 at a cost of approximately $1,000 per space. ICF assumed 10% of construction as maintenance.

6.6.3 Insurance

Additional tractor-trailer sets have value whether they are on the road or not. Though incremental insurance costs are predominantly associated with changes in the VMT, a portion of the insurance cost is associated with the intrinsic value of the change in the capital stock represented by the change in the number of tractor-trailer sets. NERA estimated a value of $2,549 per new driver per year in insurance costs based on ATA data, and we used this estimate in this analysis as well.[60] Industry experts estimated that perhaps 25% of this cost is associated with the intrinsic value of the truck, i.e., fixed cost per driver. The remainder is assumed to be variable with changes in VMT. ICF assumed that no direct change will occur in the variable portion of insurance costs since overall VMT is assumed to remain the same. The end result is a change of $637.25 per driver per year, or, following the example in Section 6.5.1, $6.3725 MM per year.

6.6.4 Maintenance

Analogous to the issue of insurance, additional tractor-trailer sets require some regular maintenance whether they are on the road or not. Though incremental maintenance costs are predominantly associated with changes in the VMT, a portion of the maintenance cost is associated with regular safety inspections and other routine, scheduled maintenance represented by the change in the number of tractor-trailer sets. Industry experts estimated a value of $8,500 per new tractor-trailer per year in maintenance costs and that perhaps 25% of this cost is associated with fixed maintenance costs per truck. The remainder is assumed to be variable with changes in VMT. The portion of the maintenance cost associated with new trucks is negated by changes in VMT in the rest of the fleet to yield no direct net change in VMT, and, hence, no change in the variable portion of maintenance costs. The end result is a change of $2,125 per truck per year, or, following the example in Section 6.5.1, $21.25 MM per year.

6.6.5 Recruitment

The need for more or fewer drivers will have an impact on recruitment costs associated with the hiring of new drivers. Rodriquez, et al. (1998),[61] surveyed 15 long-haul, for-hire trucking firms to determine the average costs associated with driver turnover, or churn. The study estimated an average cost to firms of $5,423, as summarized by cost category in the first three columns of Exhibit 6-10. ICF excluded the costs and profits from idle equipment and the production loss due to churn since equipment costs are explicitly modeled and VMT is assumed to remain constant. ICF also assumed that 75% of the advertising and staff labor costs are based on fixed annual budgets, where only 25% is variable based on the change in number of new drivers to be recruited. Firms are likely to have exhausted the most important marketing channels to them given the high industry churn rate. Administrative support (Staff

[60] Based on data from *Motor Carrier Financial and Operating Statistics, 1998*.

[61] *The Costs of Driver Turnover*, Upper Great Plains Transportation Institute, North Dakota State University, April 2000. Average values for churn-related costs ranged from $6,400 to $8,600 per hire, with an average of $8,234 per hire. However, ICF evaluated the averages as reported in the study for each cost category and the average number hires to determine the value of $5,423 per hire. Values in other surveys reviewed by NERA ranged from $2,000 to $20,000.

Labor) is assumed to be characterized by a high degree of automation, with the 25% assumption used to cover the fact that some back-office recruiting labor was included in this category by Rodriquez, et al. The rest of the costs are assumed to be fully variable with a change in the number of new drivers. The result is an incremental cost of $1,610 per hire as compared to the average of $5,423 based directly on the survey results.

Exhibit 6-10
Cost of Driver Churn Based on Rodriquez, *et al.* (1998)

Average Costs Per Firm	Total Cost	Per Hire*	ICF Per Hire	ICF % Fixed
Advertising	$446,000	$340	$85	75%
Staff Labor	$1,063,000	$811	$203	75%
Testing Fees	$193,000	$147	$147	0%
Recruitment Fees	$580,000	$442	$442	0%
Orientation Fees	$323,000	$246	$246	0%
Training Fees	$543,000	$414	$414	0%
Referral/Sign On Bonus	$94,000	$72	$72	0%
Costs for Idle Equipment	$2,313,000	$1,764		
Lost Profits Due to Idle Equipment	$705,000	$538		
Production Loss Due to Turnover	$849,000	$648		
Totals	$7,109,000	$5,423	$1,610	

*Based on survey average of 1,311 hires per firm

The cost per driver is multiplied by the change in the number of drivers in the first year. In subsequent years, the cost per hire is multiplied by the change in the number of new drivers times the assumed churn rate for drivers. Estimates of churn rates vary from 25% to over 100% depending on the survey. ICF employed the churn rate of 25% assumed by NERA (2001) for purposes of this analysis.[62] Following the example in Section 6.5.1, the cost in Year 1 is $1,610 * 10,000 drivers, or $16.10 MM. The cost in subsequent years is equal to $16.10 times the churn rate of 25%, or $4.02 MM per year.

[62] NERA claims this is a conservative assumption based on survey data indicating 25% churn per *quarter* for TL and 4% for NTL carriers, or ~75% annually across all driver types (*Trucking Activity Report*, June 2000, ATA). ICF also reviewed a compendium of surveys compiled by J.J. Keller & Associates ("What Matters to Drivers", Neenah, WI, 1997) which generally confirms the range of estimates cited by NERA.

7. MODE-SHIFT ANALYSIS

In determining the effects of the HOS rules on the mode split between truck and rail, we used the Logistics Cost Model (LCM) developed by Paul Roberts. The LCM is a computer model that determines the total logistics cost of transporting a product from a vendor to a receiver. It is an updated variant of models developed by Mr. Roberts for the Association of American Railroads (AAR) and the Federal Highway Administration. The model determines the lowest cost for ordering, loading, transporting, storing, and holding a product. The shipper is assumed to select the alternative that minimizes total logistics costs. Total logistics cost in this case includes the costs occasioned by service frequency, transit time, reliability, loss and damage, spoilage and other service-related factors occurring during ordering, transport or storage.

The analysis was limited to movements of 250 miles or more. This was done on the grounds that the probability of switching traffic from truck to rail is effectively zero for moves under 250 miles. Most authorities would assert, in fact, that this probability is quite low for shipments under 500 miles. Two hundred fifty miles was chosen as a minimum, however, to ensure a thorough analysis.

We exercised the model over a range of changes in truck prices from a 2.0 percent decrease to a 2.0 percent increase. From this analysis we were able to estimate a price elasticity of –1.4. This means that, for a 1.0 percent change in trucking rates, there is 1.4 percent change in truck shipments, truck shipments increasing with a rate decrease and diminishing with a rate increase. This measure of elasticity was used, in turn, to estimate impacts on truck and rail traffic for each of the HOS rule options.

Details of the computational method and data used are presented in Appendix D.

8. ANALYSIS OF CHANGES IN CRASHES

This chapter opens with background information on the relationship of sleep and fatigue to crash risks, and then develops estimates of baseline levels of fatigue-related crashes. Models that relate sleep and work patterns to fatigue using explicit functions are then discussed and compared, leading to a conclusion that the use of a slightly modified version of the Walter Reed Sleep and Performance Model is an appropriate choice for assessing the relative effects of the options.

The final sections of the chapter explain how the effects of the options on motor carrier operations, described in Chapter 5, were translated into changes in crashes.

8.1 Background on Driver Fatigue, Sleep and Truck-Involved Accidents

This review draws on existing literature to describe the function of sleep and the established relationship between sleep, fatigue, shift work and performance, and CMV accidents. For the purposes of this review, fatigue is defined as the decreased ability to perform induced by a lack of adequate sleep, approximately 8 hours per 24-hour period. The review does not intend to duplicate other major literature reviews performed on the subject of sleep, fatigue and truck-involved accidents.[63] Rather, it is a targeted summary of key issues related to the analysis conducted for this study.

The key issues discussed in this literature review include:

- The Function and Physiology of Sleep
    - The Stages of Sleep
    - Physiology of Sleep
- Significance of the Timing of Sleep
- Sleep Deprivation and Sleep Debt and Impact on Performance
- Fatigue and Work
- Fatigue and Truck-Involved Accidents

8.1.1 The Function and Physiology of Sleep

Sleep is an integral part of human functioning and longevity. Not getting enough sleep leads to drowsiness and impaired concentration for the subsequent non-sleep period.[64] Too little sleep also leads to impaired memory and physical performance and reduced ability to perform on cognitive tasks. Without sleep, neurons may become so depleted in energy or so polluted with

[63] See Freund, D. 1999. An Annotated Literature Review Relating to Proposed Revisions to the Hours of Service Regulation for Commercial Motor Vehicle Drivers. OMCS, Federal Highway Administration.

[64] The information in this section and in the next section on sleep is from a National Institute of Health website http://www.ninds.nih.gov, unless otherwise noted.

byproducts of normal cellular activity that they begin to malfunction. During sleep, the body also increases its protein production, enabling the repair of damaged cells, damaged from such external elements as ultraviolet rays or stress. Sleep is crucial to this process of cell repair and to the promotion of uncompromised performance during non-sleep periods.

The Stages of Sleep

Until the 1950s, sleep was regarded as a dormant, passive part of daily life. After this time, however, sleep became to be recognized as a dynamic process with multiple states of brain activity.

There are five different stages of sleep, as measured through brain activity. These five stages are:

- Stage 1 – Sleep Onset
- Stage 2, 3 and 4 – non Rapid Eye Movement (non-REM) Sleep
- Stage 5 – Rapid Eye Movement (REM) Sleep

The brain passes through stages 1, 2, 3 and 4 (non-REM sleep) and then into stage 5 (REM sleep). The time spent in each stage varies depending on the stage and depending on the number of sleep cycles (progression through stages 1, 2, 3, 4 and REM sleep) completed in the sleep period. Approximately 50 percent of total sleep time is spent in stage 2, 20 percent in REM sleep and 30 percent in the remaining stages.

Stage 1 is the shortest phase, comprised of drifting in and out of sleep. People are easily awakened during this phase. This is also the phase where one experiences "hypnic myoclonia" where the sensation of falling is often felt. In stage 1, the body has slow muscle activity and eye movement. In stage 2, the stage in which most sleep time is spent, eye movement stops. The brain's electrical activity decreases and short bursts of rapid brain waves occasionally appear. Stage 2 is the first stage of the non-REM sleep stages. Stages 3 and 4 (called deep sleep) are also non-REM sleep stages and are characterized by very slow brain waves.

REM sleep is the next stage. This is often referred to as the "active" sleep stage. The slowed brain waves begin to accelerate, breathing becomes more rapid, irregular and shallow, eye movement begins, heart rate increases and blood pressure rises. This lighter stage of sleep is where most dreaming occurs. As the sleep period progresses, the REM sleep stage increases in length where towards the end of the sleep period, an individual may spend up to one hour in REM sleep and experience very involved dreams.

The complete sleep cycle usually takes 90 to 110 minutes. The first sleep cycles of each sleep period contain relatively short REM periods and long periods of deep sleep. As the night progresses, REM sleep periods increase in length while deep sleep (stages 3 and 4) decreases. By the end of a "normal" sleep period (defined here as approximately 8 hours), almost all sleep is spent in Stage 2 and REM sleep.

Physiology of Sleep

Most sleep experts agree that adults need between six and ten hours of sleep per 24-hour period, with most people requiring approximately 8 hours of sleep per day.[65] Sleep most naturally occurs at night, due to the human body's circadian rhythm. Circadian, or daily, rhythms operate on approximately a 24-hour cycle and are responsible for natural peaks and lulls in hormonal secretions, a heightened sense of fatigue during different parts of the day – particularly in the early morning hours and the late afternoon – and the coordination and timing of other internal bodily functions, including body temperature and sleep. Sunlight and other time cues help to set and maintain circadian cycles.

Body temperature fluctuates in accordance with other bodily fluctuations of the circadian cycle and influences the timing of sleep and sleep onset. During a single day, the body's temperature rises and falls a number of times. Body temperature rises in the early morning hours, declines in the late afternoon, rises in the evening and declines later at night. People prefer to go to bed during certain phases in the temperature cycle over others, preferring phases when the circadian temperature cycle is at the nadir (lowest point).[66] When body temperature is on the rise, the body has a greater propensity to awaken.[67] Body temperature is on the rise in the morning hours, when people on regular night sleep schedules tend to wake up. It logically follows that it is more difficult to fall asleep during these morning hours (because body temperature is rising, not falling).

The sleep/wake cycle shows that the degree of sleepiness depends on the oscillating circadian rhythm and declining linear function (increased degree of sleepiness) based on the length of time spent awake.[68] The next section discusses the impact of too little sleep.

8.1.2 Significance of the Timing of Sleep

The timing of sleep matters. Sleep duration is greatest after evening bedtimes and shortest after morning bedtimes.[69] The duration of sleep has also been found to be shorter the later in the morning sleep begins.[70] The shorter sleep duration after a morning bedtime might seem somewhat counterintuitive as a morning bedtime is often the result of sleep postponed (i.e. longer period elapsed since last period of sleep). However, this decrease can be explained by the strong influence of the circadian rhythm on sleep duration, which makes it more difficult to sleep during daytime hours than it is during nighttime hours.

[65] Pilcher, J.J., Huffcutt, A.I., 1996. Effects of sleep deprivation on performance: a meta-analysis. Sleep, 19, 318-326.

[66] Czeisler, C.A., Weitzman, E.D., Moore-Ede, M.C., Zimmerman, J.C., Knauer, R.S., 1980. Human sleep: its duration and organization depend on its circadian phase. Science 210, 1264-1267.

[67] Gillberg, M., Akerstedt, T., 1982. Body temperature and sleep at different times of day. Sleep.

[68] Akerstedt, T., Gillberg, M., 1982. Displacement of the sleep period and sleep deprivation. Human Neurobiology 1: 163-171.

[69] Akerstedt, T., Gillberg, M, 1981. The circadian variation of experimentally displaced sleep. Sleep 4: 159-169.

[70] Akerstedt, T., Gillberg, M., 1982. Displacement of the sleep period and sleep deprivation: implications for shift work. Human Neurobiology 1, 163-171.

A number of studies have shown that duration of sleep is influenced by the time of day of sleep. A survey found that night workers, who by default must sleep in some part, or entirely, during the day, slept three hours less than the recommended eight hours required to prevent sleep debt.[71] Another study found that night workers (shift starting around 2200 or 0000) slept on average 3.3 hours less than their day-working counterparts (shift starting around 0800), sleeping 4.3 hours and 7.6 hours respectively.[72] These data demonstrate that people who rely on daytime sleep for a significant part of their rest are experiencing less total sleep. This finding was supported by an analysis of survey data conducted for this report, and described in Appendix G.

8.1.3 Sleep Deprivation and Sleep Debt and Impact on Performance

Sleep deprivation occurs when an individual sleeps two or more hours less than the optimal amount during any one sleep episode, eight hours being the standard optimal amount subject to significant variation by individual. Sleep deprivation over a series of sleep periods leads to sleep debt, the accumulated sleep loss over the course of time.[73] The discussion in this section presents the results of a number of studies and the implications of sleep deprivation and sleep debt on performance based on the available literature.

Sleep deprivation and sleep debt have a number of consequences for performance. Sleep deprivation over a couple of days leads to slower response times and decreased initiative.[74] After one sleepless night, cognitive performance may decrease 25% as compared to the performance of non-sleep deprived individuals.[75] After the second sleepless night, performance on cognitive tasks may decrease to nearly 40% the potential level. A meta-analysis found that people who are chronically sleep deprived (i.e., have substantial sleep debt) performed at the 9th percentile of non-sleep-deprived subjects.[76]

Individuals switching from an irregular to regular schedule do not immediately achieve improved fatigue levels. Sleep deprived individuals with irregular sleep schedules (as could be the case with truck drivers) who regularized their sleep schedules but suffered sleep loss in the process experienced an increase in daytime sleepiness and a concomitant deterioration in concentration ratings, immediately after regularizing their sleep schedule.[77]

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[71] Caldwell, J.L., Gilreath, D.S., 2000. A survey of subjective sleep length of shift workers based on time of day of sleep onset. Presented at the 14th Annual Meeting of the Associated Professional Sleep Societies.

[72] Akerstedt, T., Gillberg, M., Torscall, L, Froberg, J., 1980. Oregelbunndna arbetstider: Sammanfattning av en undersokning av turlistetidsarbetande lokforare. Reports from the Laboratory for Clinical Stress Research, No 132. In Akerstedt, T., Gillberg, M., 1982. Displacement of the sleep period and sleep deprivation: implications for shift work. Human Neurobiology 1, 163-171.

[73] Jha, A.K., Duncan, B.W., Bates, D.W., 2001. Fatigue, Sleepiness and Medical Errors, for the Agency for Health Care Research and Quality. Evidence Report/Technology Assessment, No. 43.

[74] Koslowsky, M., Babkoff, H., 1992. Meta-analysis of the relationship between total sleep deprivation and performance. Chronobiol Int, 9, 132-136.

[75] Krueger, G., ed., 1989. Sustained work, fatigue, sleeps loss and performance: a review of the issues. Work and Stress, 3.

[76] Pilcher, J.J., Huffcutt, A.I., 1996. Effects of sleep deprivation on performance: a meta-analysis. Sleep, 19, 318-326.

[77] Manber, R., Bootzin, R., 1991. The effects of regular wake-up schedules on daytime sleepiness in college students. Sleep Research 20, 284.

These findings suggest that routine sleep schedules that see the individual sleeping an adequate number of hours (approximately 8 hours, varying by individual) during approximately the same time during a 24-hour period, facilitate daily functioning at unimpaired performance levels.

8.1.4 Fatigue and Work

Workers experience a number of different types of fatigue while on the job. The three major types of fatigue affecting work performance are industrial, cumulative and circadian.[78] These types of fatigue are described below, focusing on the literature relating to truck drivers.

Industrial fatigue results from working continuously over an extended period of time without proper rest, often referred to in the literature as fatigue resulting from time-on-task. For example, a truck driver who has been driving for six hours, without a break, might be subject to industrial fatigue. Some studies have shown performance to decrease as time on task increases.[79] Time-on-task problems could be exacerbated by sleep loss, even in the early stages of the task. One study concluded that for sleep deprived individuals, performance is compromised even at early stages of performance of a monotonous task if the situation is undemanding and boring. This study suggests that the effect of sleepiness becomes immediately evident in the form of reduced vigilance.[80,81]

Cumulative fatigue arises from working for too many days on any protracted, repetitive task without any prolonged break. This fatigue results from a lack of alertness brought on by familiarity and boredom with the task at hand. A truck driver could experience cumulative fatigue, for example under the current HOS rules, after driving for 12 hours, taking eight hours off and then driving another 12 hours (driving a total of 24 hours in a 32 hour period).

Circadian fatigue is a function of the circadian rhythm. Fatigue is greatest when approaching or at the nadir of the circadian cycle, where the body is least vigilant. The truck accident rate is much higher during the early morning hours than during any other time of day,[82] supporting the circadian effect hypothesis that accidents are more likely to occur when the human body is least vigilant.[83]

Night and rotating shift workers are especially susceptible to being fatigued on the job.[84,85,86] Permanently assigned graveyard-shift workers sleep between 5.8 to 6.4 hours per day.[87]

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[78] Saccomanno, F.F., Yu, M., and Shortreed , J.H., 1995. Effect of driver fatigue on truck accident rates. *Urban Transport and the Environment for the 21st Century*, ed. Sucharov, L.J., Southampton, UK: Computational Mechanics Publications, 439-446.

[79] Dinges, D.F., Kribbs, N.B., 1991. Performing while sleepy: effects of experimentally induced sleepiness. In Monk, T. (ed.) Sleep, sleepiness and performance. New York: John Wiley & Sons.

[80] "Vigilance" was measured through a 34-minute visual vigilance test.

[81] Gillberg, M., Akerstedt, T. 1998. Sleep loss and performance: no "safe" duration of a monotonous task. Physiol Behav 64(5), 599-604.

[82] Harris, W., 1978. Fatigue, circadian rhythm and truck accidents in Vigilance: Theory, Operational Performance and Physiological Correlates, ed. Mackie, R.. New York, NY: Plenum Press, 133-146.

[83] See previous section entitled "The Biology of Sleep" for further discussion of the circadian effect.

[84] Akerstedt, T., 1988. Sleepiness as a consequence of shift work. Sleep, 11, 17-34.

[85] Mitler, M.M., Carskadon, M.A., Czeisler, C.S., Dement, W.C., Dinges, D.F., Graeber, R.C., 1988. Catastrophes, sleep and public policy. Sleep 11 (1), 100-109.

Rotating shift workers, such as many truck drivers, sleep even less when they work a night shift (5.25 to 5.5 hours). Shift workers experience disturbances in their circadian rhythm, as measured by changes in hormonal levels;[88] they are also less alert during nighttime shifts and perform less well on reasoning and non-stimulating tasks than non-shift workers.[89] Though nightshift work for many workers is regular (i.e., the same schedule is kept over time), truck drivers often have irregular schedules which can amplify the effects of circadian, cumulative and industrial fatigue and increase the risk of fatigue-related accidents.

8.1.5 Fatigue and Truck-Involved Accidents

Fatigue increases over the duration of trips, regardless of the driving schedule[90] and total driving time has a significant effect on crash risk though there is variation on the point at which crash risk increases significantly, depending on the study methodology.[91,92] A study of industrial fatigue in truck drivers found that in over 65% of cases, truck accidents took place during the second half of a trip, regardless of trip length.[93] An analysis of Bureau of Motor Carrier Safety data in the 1970s found that about twice as many accidents occurred during the second half of trips than during the first half, regardless of trip duration.[94] Another study found that the risk of accident increased after the fourth hour of driving and peaked after nine hours of driving.[95] These studies are among many finding that industrial fatigue plays a role in predisposing truck drivers to accidents.

Determining the magnitude of this effect, however, and ensuring that other factors (such as sleep history and time of day) have been factored out, is quite difficult.

Researchers have long asked how long can a person sustain work effort at different tasks without lengthy breaks, before his/her performance of those tasks becomes unacceptably degraded. There has always been a notion that by itself, sustained performance at a task (Time on Task or TOT) eventually results in a "fatiguing effect" manifesting itself in the form of slower response

[86] Gold, D.R., et al., 1992. Rotating shift work, sleep and accidents related to sleepiness in hospital nurses. American Journal of Public Health 82 (7), 1011-1014.

[87] Bonnet, M.H., Arand, D.L., 1995. We are chronically sleep deprived. Sleep 18 (10), 908-911.

[88] Akerstedt, T., Levi, L., 1978. Circadian rhythms in the secretion of cortisol, adrenaline and noradrenaline. Eur J Clin Invest 8, 57-58.

[89] Akerstedt, T., 1988. Sleepiness as a consequence of shift work. Sleep 11, 17-34; Akerstedt, T., Kecklund, G., Knutsson, A., 1981. Manifest sleepiness and the spectral content of the EEG during shift work. Sleep 14, 221-225.

[90] Williamson, A.M., Feyer, A.M., Friswell, R., 1996. The impact of work practices on fatigue in long distance truck drivers. Accident Analysis and Prevantion 28 (6), 709-719.

[91] Lin, T.D., Jovanis, P.P., Yang, C.Z., 1994. Time of day models of motor carrier accident risk, Transportation Research Record 1457, National Academy Press, Washington, DC.

[92] Frith, W.J., 1994. A case control study of heavy vehicle drivers' working time and safety. Victoria, Australia: Proceedings, 17th Australian Road Research Board Conference, Part 5, 17-30.

[93] Mackie, R.R., Miller, J.C., 1980. Effects of irregular schedules and physical work on commercial driver fatigue and performance. Human Factors in Transport Research. London, UK: Academic Press Inc.

[94] Harris, W., 1978. Fatigue, circadian rhythm and truck accidents, in ed. Mackie, R., Vigilance: Theory, Operational Performance and Physiological Correlates. New York, NY: Plenum Press, 133-146.

[95] Kaneko, T., Jovanis, P., 1992. Multiday driving patterns and motor carrier accident risk: a disaggregate analysis. Accident Analysis and Prevention 24 (5), 437-452.

times or errors of omission. Below is a short literature review of five studies about the time-on-task effect on driving and some concluding remarks.

Jones and Stein (1987)[96] attempted to provide "adjusted odds ratios" to different categories of "length of time in driving" (TOT), assigning a baseline value of 1.0 to the relative risk of the likelihood of crashes attributable to a driving time of from 0 to 2 hours; and they presented an increased odds ratio of 1.2 for driving times of from 2 to 5 hours and also 5 to 8 hours of driving time (TOT). The work of Jones and Stein says nothing about projecting odds ratios for driving more than 8 hours, something at the root question of the entire discussion of truck driver HOS.

Lin, Jovanis, and Yang (1993)[97] introduce a time-dependent logistic regression model formulated to assess the safety of motor carrier operations. They describe their model as being flexible, allowing the inclusion of time-independent covariates, time main effects, and time-related interactions. The model estimates the probability of having a crash at time interval t, subject to surviving (not having a crash) before that time interval. Covariates tested in the model in this paper include consecutive driving time, multiday driving pattern over a 7-day period, driver age and experience, and hours off duty before the trip of interest. Although the work of Lin, Jovanis, and Yang has some appeal in the conduct of our study, their methods and modeling are of some concern in that they do not model beyond the 8-9 hours of driving incidents, something which is obviously needed to examine the HOS alternatives.

In their description of nine logistic regression modeling attempts Lin, Jovanis, and Yang state that driving time (TOT) has the strongest direct effect on accident risk. The first 4 hr consistently have the lowest crash risk and are indistinguishable from each other. Accident (crash) risk increases significantly after the fourth hour of driving, by approximately 50% or more, until the seventh hour. The 8th and 9th hours show a further increase, approximately 80% and 130% higher than the first 4 hours.

Campbell (1988)[98] states that there is a steady increase in the probability of accident involvement with the number of hours driving. To look into this, Campbell used data from accident reports filed with the Office of Motor Carriers and extracted the time of day that the accident occurred, the number of hours driving at the time of the accident, and the intended driving period had the accident not occurred. The accidents that were coded as the driver having dozed at the time of the accident were used to determine the time-on-task effect. The problem with this is that not all of the crash data was included and crashes may have been caused by fatigue yet the driver was not dozing at the time. It was concluded that the crossover point in which the proportion of accidents in the latter hours of driving is more frequent occurs around four hours of driving.

[96] Jones, I.S. & Stein, H.S. (1987). Effect of driver hours of service on tractor-trailer crash involvement. (Proceedings paper). Arlington, VA: Insurance Institute for Highway Safety.

[97] Lin, T.D., Jovanis, P.P. & Yang, C-Z. (1993) Modeling the safety of truck driver service hours using time-dependent logistic regression. Transportation Research Record, 1407 1-10.

[98] Campbell, K. L. 1988. Evidence of fatigue and the circadian rhythm in the accident experience. Michigan University, Ann Arbor, Transportation Research Institute, Center for National Truck Statistics. 29 p. UMTRI-77933

O'Neill et al. (1999)[99] studied the operating practices of CMV drivers, as well as the relationship of these practices to driver fatigue. Drivers worked a 14-hour on, 10 hour off schedule driving a simulator for a 5-day week. Two 30-minute breaks and a 45-minute lunch break were taken during the day at regularly scheduled times. The observed recovery effect of the breaks was rather striking. The effects of 6.5 hours of driving were virtually reduced to the starting levels by a 45-minute break (O'Neil et al., 1999). It is important to keep in mind that while this recovery effect is remarkable, it occurred under very strict, adhered to conditions. This effect took place under daytime driving conditions, the 14 hours on/10 hours off driving schedule that allowed for adequate rest, and scheduled breaks. It cannot be said with a reasonable degree of certainty that this recovery effect would occur in the same way under different conditions.

Wylie et al. (1996) [100]studied four different driving conditions to test several driving fatigue questions: a 10-hour "baseline" daytime schedule, a 10-hour "operational" or rotating schedule, a 13-hour nighttime start schedule, and a 13-hour daytime start schedule. The authors concluded that hours-of-driving (TOT) was not a strong or consistent predictor of observed fatigue. Interestingly, there was a positive correlation between driver's self-ratings of fatigue and the number of hours driving within a trip while objective performance did not indicate a positive correlation.

Based on the literature reviewed, the time-on-task effect was not quantifiable independent of and in addition to the circadian and recovery/decrement recovery factors. Therefore, the TOT effect was not used as a separate factor in the analysis of the options conducted for this report.

Another important and relevant factor is time of day and continuity of sleep. Numerous studies have found an increased crash risk for truck drivers associated with night-time driving.[101,102] In a study of a group of drivers involved in single-vehicle accidents, almost twice as many of their accidents occurred in the early morning hours between midnight and 0800 hours (66%) as during the rest of the day (34%).[103] Accidents and workplace errors from studies concerning road, maritime and industrial operations show a peak at 0300.[104] Additionally, the continuity of sleep is significant. An elevated fatal crash risk was identified for drivers that split the required 8 hours off-duty into two sessions in a sleeper berth.[105]

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[99] O'Neill, Krueger, G.P., Van Hemel, S.B., & McGowan, A.L. (1999). Effects of operating practices on commercial driver alertness. (FHWA-OMC Technical Report No. FHWA-MC-99-140).

[100] Wylie, C.D., Shultz, T., Miller, J.C., Miktler, M.M. & Mackie, R.R. (1996). Commercial motor vehicle driver fatigue and alertness study. (FHWA Technical Report No. MC-97-002). Washington, DC: Federal Highway Administration.

[101] Jovanis, P.P, Kaneko, T., Lin, T.D., 1991. Exploratory analysis of motor carrier accident risk and daily driving patterns. 70th Annual Meeting of Transportation Research Board, Transportation Research Board, Washington, DC.

[102] Lavie, P., 1986. Ultrashort sleep-waking schedule, III. 'Gates' and 'forbidden zones' for sleep. Electroencephalography and Clinical Neurophysiology 63, 414-425.

[103] Harris, W., 1978. Fatigue, circadian rhythm and truck accidents in Vigilance: Theory, Operational Performance and Physiological Correlates, ed. Mackie, R.. New York, NY: Plenum Press, 133-146.

[104] Folkard, S., 1997. Black times: temporal determinants of transport safety. Accident Analysis and Prevention 29 (4), 417-430.

[105] Hertz, R.P., 1988. Tractor-trailer driver fatality: the role of nonconnective rest in a sleep berth. Accident Analysis and Prevention 20 (6), 429-431.

An arduous work schedule has also been identified as increasing the risk of truck involved accidents.[106] One study found that drivers on a regular 13-hour daytime-start driving schedule slept for 5.1 hours while drivers on a 10-hour daytime start driving schedule slept 5.4 hours.[107] While this study only looked at daytime-start schedules, the relationship between time-off duty and time spent asleep is remarkable. Drivers with 11 hours off spent 5.1 hours asleep (and an additional .4 hours in bed) while drivers with 14 hours off spent 5.4 hours asleep (and an additional .4 hours in bed). The study cites the fact that drivers on the 13-hour schedule were within 10 minutes of their sleep laboratory and thus may have been able to get more sleep than otherwise. The sleep numbers for both groups are likely to be high because each were able to obtain their principal sleep during optimal times of the day (in accordance with the circadian rhythm), starting late in the evening and ending early in the morning. It is possible that given the same schedule durations, these drivers could have slept less if conditions were different (e.g., if the schedule necessitated nighttime driving, if the drivers lived (or the sleep center was) further from their daily terminating point).

8.1.6 Conclusion

Driving requires sustained attention; it is an inherently fatiguing task in its monotony and repetition.[108] For many commercial motor vehicle drivers, the inherently fatiguing task of driving is compounded by fatigue caused by working long, irregular hours that conflict with natural circadian rhythms.[109] Because of the economic incentives for rapid goods transport, many drivers may be unable to obtain sufficient, sustained, restorative sleep and may subsequently experience sleep deprivation or accumulate a sizable sleep debt. Sleep deprivation and sleep debt, as shown through this review, can lead to an increase in the risk of accidents through impaired performance. This fact supports the need to provide CMV drivers with conditions that make it possible and likely for them to get sufficient sleep, though even ideal conditions could not eliminate all fatigue-related crashes.

8.2 Estimates of Motor Carrier Crashes Due to Fatigue

This section presents estimates of the number of crashes involving trucks, by severity of crash. In addition, it discusses methods for estimating the percentage of crashes attributable to fatigue, and the results of applying those methods.

8.2.1 Data and Approach to Crash Analyses

The National Highway Traffic Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS) and General Estimates System (GES) databases along with the Federal Motor Carrier Safety Administration Motor Carrier Management Information System (MCMIS) Crash File were reviewed for the years 1997 through 2000. They provided the primary basis for crash

[106] McCartt, A.T. et. Al, 1999. Factors associated with falling asleep at the wheel among long-distance truck drivers. Accident and Analysis Prevention 32,493-504.

[107] Wylie, C.D., Shultz, T., Miller, J.C., Mitler, M.M., Mackie, R.R., 1996. Commercial motor vehicle driver fatigue and alertness study.

[108] Monk, T.H., Folkard, S., 1979. Shiftwork and performance. Human Factors 21 (4), 483-492.

[109] McCartt, A.T., Rohrbaugh, H.W., Hammer, M.C., Fuller, S.Z., 2000. Factors associated with falling asleep at the wheel among long-distance truck drivers. Accident Analysis and Prevention 32, 493-504.

estimates. Other databases including the MCMIS Census File, National Motor Carrier Directory (NMCD), and Bluebook were used to categorize crashes by motor carrier firm operations so that the resultant crash data could be linked to the industry profile and schedule/risk analyses used to evaluate the potential effects of proposed changes to the hours of service regulations.

The crash analysis began with an attempt to extract commercial motor vehicle crashes from the three crash data files. Key variables included the state, and date of the crashes; vehicle type and configuration; motor carrier census number; total vehicles, occupants, injuries and fatalities; and driver, vehicle and environmental factors associated with the crashes. The goal was to be able to establish a profile of carriers/vehicles involved in crashes with particular attention placed on the apparent contributing factors or accident causes. There was an attempt made to eliminate "other driver" and environmental factors leading to the crash. This was done to extract truck crashes where the driver would probably be considered not "at fault" from the overall set of crashes. The key issue was to determine the extent to which CMV driver fatigue or associated factors could be reasonably established as a primary contributing factor in the crash.

In conducting such an analysis, it is essential that one recognize the potential weakness in using police accident reports (PARs) as the sole basis for attributing fatigue as a crash cause. The police officers who complete the reports rarely have specialized training in crash investigation or even in completing the forms. One should also note that completing the PAR is no greater than a third priority for officers who are involved in situation assessment, emergency response and victim assistance, and finally controlling and then restoring traffic flow around the crash scene. Additionally, PARs are believed to under- rather than overestimate fatigue involvement in large truck crashes.

Crashes where CMV driver fatigue is cited as a primary contributing factor should be viewed as the "minimum" number of crashes with fatigue as a cause. For this reason, the analysis was conducted to develop a more reasonable estimate of the total number of fatigue-related crashes. An analysis of data for crashes where driver inattention was cited within the PAR was used to apportion part of those crashes as fatigue-related. This conclusion was drawn from a comprehensive report of Short Haul drivers that attributed more than 20% of all inattention crashes to driver fatigue.

Historical Crash Data Summary

In order to develop estimates of the total cost of truck crashes in recent years, the FARS, GES and MCMIS Crash File databases were reviewed to derive national summary totals of crashes by type, fatalities, and injuries. Generally, crashes are defined by whether or not they involve fatalities suffered by vehicle passengers or non-occupants (pedestrians), reported injuries where no fatality was involved, or property damage with no fatalities or injuries (property damage only crashes.). The MCMIS database tends to contain more detailed information about the vehicle configuration or cargo carried and is especially useful for determining the identity of the motor carrier involved in a crash. However, there has been an historical (although recently narrowing) undercount of truck crashes noted in the MCMIS database versus FARS. Comparably, there still seems to be a substantial undercount of injury and property damage only (PDO) crashes in MCMIS versus the national estimates derived in the NHTSA GES database. Part of the difference is related to the definitions used to include PDO crashes in GES versus the MCMIS datasets.

The FARS database is considered the best source of fatal crash information since it is a census of all fatality involved motor vehicle crashes occurring within the United States. It was used to develop estimates of the total fatal crashes involving trucks, the total fatalities (broken down by truck, other vehicle, or non-occupants) and the numbers of combination and large single unit trucks involved. Data were reported for calendar years 1997 through 2000 and for the average over the four-year period.

National estimates of truck crashes that do not involve a fatal injury were derived from the GES files. Crashes, total injuries and trucks involved were reported for the injury crashes while total crashes and trucks involved were reported for the PDO crashes. The GES estimates are based on a stratified national sample where each crash is assigned a sampling weight according the stratum from which it is reported. The GES estimates are always rounded to the nearest thousand crashes, vehicles, or injuries. These national estimates are provided below.

Exhibit 8-1
Large Truck Crashes by Year

	1997	1998	1999	2000	average
Fatal Crashes	**4,614**	**4,579**	**4,560**	**4,519**	**4,568**
Total fatalities	5,398	5,395	5,380	5,211	5,346
Truck occupants	723	742	759	741	741
Other vehicle occupants	4,223	4,215	4,180	4,060	4,170
Non vehicle occupants	452	438	441	410	435
Trucks involved	4,917	4,955	4,920	4,930	4,931
Comb trucks involved	3,711	3,747	3,713	3,708	3,720
Single unit trucks involved	1,206	1,208	1,207	1,222	1,211
Single vehicle crashes	847	803	808	802	815
Injury Crashes	**92,000**	**85,000**	**95,000**	**96,000**	**92,000**
Total injuries	131,000	127,000	142,000	140,000	135,000
Trucks involved	96,000	89,000	101,000	101,000	96,750
Comb trucks involved	53,000	51,000	57,000	52,000	53,250
Single unit trucks involved	43,000	38,000	44,000	48,000	43,250
Single vehicle crashes	16,000	15,000	17,000	17,000	16,250
PDO Crashes	**325,000**	**302,000**	**353,000**	**337,000**	**329,250**
Trucks involved	337,000	318,000	369,000	351,000	343,750
Comb trucks involved	197,000	178,000	184,000	179,000	184,500
Single unit trucks involved	141,000	140,000	185,000	173,000	159,750
Single vehicle crashes	95,000	91,000	98,000	104,000	97,000
TOTAL	**421,614**	**391,579**	**452,560**	**437,519**	**425,818**

Source: FARS and GES databases.

MCMIS Data Analysis

In order to complete the baseline analysis, it was necessary to determine what proportion of truck crashes could be attributed to truck driver fatigue. The MCMIS Crash File for 1997 through 2000 was used. Bus and unknown vehicle type records were eliminated from the database and the "apparent driver condition" variable was used to code the data records for which "fatigue" or "asleep" had been cited as contributing factor in the crash. The "raw" fatigue/asleep crash estimates for 1997 through 1999 was approximately 1.31% of all truck crashes with the number dropping in 2000 to less than 1%. These very low values could seem to indicate a minimal fatigue rate for truck crashes. However, closer examination of the data and direct benchmarking to alternative data sources point to numerous deficiencies in such a simple analysis.

As a matter of policy, the "apparent driver condition" variable has been eliminated from the National Governor's Association (NGA) required list of reportable data elements for commercial vehicle crash reports in the SAFETYNET 2000 (Version 2) reporting system. This was in large part due to historical under-reported and non-reported values for this variable. In 38% of the 2000 data records, the driver condition variable was missing compared to less than 10% of the time in earlier years. In the earlier years, the data field was reported as "unknown" rather than missing in about 7% of all crash records. A problem arises in that "appeared normal" and "unknown" are both coding options, but for analytic purposes, it is difficult to ascertain whether a blank value for this variable should be interpreted as "normal", "unknown" or "not interpretable". Previous estimates of driver fatigue associated with truck crashes have been hampered by this serious data quality problem.

A state-by-state examination of the data also showed several systematic problems in the reporting of the driver condition variable. Driver condition was not reported in truck crash data records from the States of Massachusetts, Oregon, South Carolina or Virginia in any of the years of data examined. Additionally, fatigue/asleep was never reported as a factor in truck crashes in the States of Colorado, Michigan, New Mexico or Wisconsin. These data reporting problems result in a logical inconsistency in calculating fatigue involvement rates for truck crashes. If it is impossible to add a fatigue event in the numerator of the national fatigue crash rate, then the data from these States should not be included in the denominator of the rate calculation. The problem grows worse in more recent years with many more States opting to not report apparent driver condition at all. For these reasons, the MCMIS database should not be used to derive estimates of fatigue-involved truck crashes.

FARS Data Analysis

As an alternative to using the MCMIS data, FARS truck crash data for the years 1997 through 2000 were reviewed. The FARS database contains information for crashes involving at least one associated fatality in the involved truck, in another vehicle, or a pedestrian. The FARS database has been used as a benchmark for the MCMIS database fatal crashes since the requirement for motor carrier self-reporting of crashes was ended in the early 1990's. The FARS database has historically been held in high regard because of the NHTSA protocols for editing and coding the data elements within the data records.

In order to use the FARS database for analysis of fatigue related truck crashes, several key issues have to be examined. Is it reasonable to extend fatigue–related crash estimates from fatal crashes to injury and property damage only crashes? Since the FARS database contains data elements for reporting up to four driver factors, how should these multiple responses be handled? Are there data reporting issues for the FARS dataset comparable to those encountered in the MCMIS data set?

The FARS database is limited to crashes involving a traffic fatality. By definition, these crashes are more severe since the fatal outcome has a higher social or economic cost than would a comparable crash resulting in (perhaps minor) injuries or damages to property only. Fatal crashes certainly have other characteristics that separate them from injury only or PDO crashes, especially those factors associated with speed and type of impact. In truck crashes, the "other vehicle" occupant is almost six times more likely to die in the crash than a truck occupant, so it is not clear to what extent fatal truck crash characteristics can be reasonably generalized to injury or PDO crashes.

This question is difficult to answer with the data available. A review of MCMIS fatigue involved crashes by crash type reveal that there was an historical trend of fatigue being reported in fatal crashes more than in injury and property damage only crashes. The overall data reporting problems for MCMIS fatigue crash rates also present interpretation problems for this feature of the data. Data for the year 2000 should not be used since the apparent driver condition variable had already stopped being used. However, for 1999 and 1998, fatigue involvement in fatal crashes did exceed that reported in injury crashes or PDO crashes.

Another estimate of the relative prevalence of fatigue in the three types of crashes could be drawn from the GES data. The GES database serves as a very good source of national estimates of total crashes and for crashes with certain characteristics (such as number of occupants or injuries, or by vehicle type). However, some specific details of the crash cannot be estimated very reliably. Derived from state databases of police accident reports, the GES suffers from some of the same faults as the MCMIS. There may be only one (if any) of the driver condition variables included in the reports and fatigue may not always be a coded or reported factor. In the 2000 database, however, fatigue was cited as a contributing factor in 1.46% of all the fatal crashes, 0.94% of the injury only crashes and 0.65% of the PDO crashes. These percentages were drawn from the raw non-weighted sample. Additionally, the data were not edited for missing values or adjusted for any other factors related to the data reporting in the files.

With such small percentages reported in the MCMIS and GES databases, there is some uncertainty in concluding that FARS data for fatigue involvement in crashes can be extended to the injury and PDO crashes. In real terms, the differences are negligible. In percentage terms the differences could be viewed as substantial. However, the FARS database contains the most detailed and highest quality data. There is also evidence that the historical underreporting of fatigue involvement in FARS would tend to provide conservative estimates regardless.

Since the FARS database contains four different fields for reporting driver factors contributing to the crash, there was some initial concern that this could introduce an upward bias in the reporting of fatigue involvement in crashes. For the years 1997 through 2000 this appears not to be the case. In most all of the cases where fatigue was cited as a factor and there were other factors cited, the fatigue code tended to occur first in the list. Additionally, it was reported with a factor that would not confound the results reported in this analysis. The two most common other factors reported were "ran off road" and "inattention". These accounted for a large proportion of the multiple factors cases.

Finally, from the standpoint of data quality, some factors ought to be considered when viewing the FARS data to assure that cases are not included in the denominator of the rate calculations, unreasonably biasing the estimates downward. Examination of the individual data records indicated that there are several sets of crashes that it seems unreasonable to consider in calculating the fatigue involvement rate. For one set of crashes, many of the key variables (vehicle configuration, body type, harmful events, driver charges, impact details, etc.) are coded as "9's", which means unknown or unreported. In all of these cases the driver contributing factors are coded as "99". In another set of data records, the individual crashes can be matched back to the MCMIS file where the contributing factors are missing because of state data reporting systems and procedures. These appear in the FARS database with driver factors coded as "0's". Eliminating these records from the analysis set was a prerequisite to calculating the proportion of crashes with motor carrier fatigue as a contributing factor.

The final step in completing this analysis was to examine each fatal crash involving a large truck and use the factors cited to determine whether "fault" was attributed in the crash. Crashes were categorized as whether the "other" (non-truck) driver was determined to be at fault and whether the truck driver was determined to be at fault. Two other values for these variables were also considered and reported below. If inclement weather was cited that is so reported. If no fault was assigned for the crash, that was also reported. One should note that since weather conditions and multiple drivers may interact to provide multiple responsible conditions or persons, the percentages for fault attribution could add up to more than 100%. In all of the years of reported data, that is the case. One important fact to note from these attribution data, is that the "other driver" was deemed to be at fault almost twice as often as the truck driver.

The fatigue attribution for the FARS crash data is shown in Exhibit 8-2. The edited data provide us with an estimate of between 6.60% (2000) and 8.21% (1999) for the period examined. These fatigue numbers were adjusted further to account for a systematic phenomenon noted by Hanowski in his study of local/short haul drivers.[110] In that study, fatigue was determined to be a contributing factor in 20.8 percent of the incidents where the driver was judged to be at fault due to inattention. When at fault, their PERCLOS (percent eyelid closure) values prior to the incidents were significantly higher than for other types of critical incidents.

Exhibit 8-2
Fatigue-Related Fatal Crashes

	1997	1998	1999	2000	Average
MCMIS raw	1.34%	1.31%	1.31%	0.75%	1.18%
MCMIS (adjusted)	1.65%	1.65%	1.80%	1.47%	1.64%
FARS fatigue	7.14%	7.04%	8.21%	6.60%	7.25%
FARS inattention	4.19%	4.08%	4.47%	4.59%	4.33%
FARS fatigued inattention	0.87%	0.85%	0.93%	0.90%	0.89%
FARS all fatigue	**8.01%**	**7.89%**	**9.14%**	**7.55%**	**8.15%**

Source: MCMIS and FARS databases and Faucett and ICF calculations. Percentages may not add due to rounding.

Exhibit 8-2 shows the proportion of crashes in which inattention was cited as a major contributing factor. The final fatigue figures provided use the total fatigue cited crashes plus

[110] Hanowski, R., Wierwille, W., Gellatly, A., Early, N., and Dingus, T. *Impact of Local/Short Haul Operations on Driver Fatigue: Final Report,* FMCSA, FMCSA No. DOT-MC-00-203, NTIS No. PB2001-101416INZ, Washington, D.C., Sept. 2000.

20.8% of the inattention caused crashes to establish the final estimate of crashes that can be reasonably regarded as due to truck driver fatigue.[111]

8.2.2 Estimation of Crashes by Large Truck Firm Operations Type

To estimate the relative involvement of large trucks in crashes by operations type, crash records must contain specific information about the trucks involved. Crashes can be classified by the operations of the vehicles or firms involved using either the actual characteristics of the trip in which a crash occurred or the identity of the motor carrier involved, assuming that the firm identifying number can be matched to a data source in which motor carriers are classified by their operations.

The most commonly cited crash databases do not contain trip-specific characteristics. The ideal information for determining whether a crash occurred in long- versus short-haul operations would be the starting and intended ending point of the trip in which the crash occurred. The calculated distance between those two points would provide with certainty the ability to classify the trip according to any specified cut-off point selected for differentiating between long- versus short-haul operations.

A very good indicator for determining if a truck crash occurred in short haul operations may be the vehicle or equipment type. Dump trucks, garbage trucks and concrete mixers are rarely involved in long-haul operations. To a lesser extent, cargo tanks are somewhat restricted to short haul use. Flatbed trucks, straight trucks, and vans or enclosed boxes are widely used in both long- and short-haul operations. This group comprises a substantial population of the cargo body types noted in truck crashes.

An alternative method for determining the operations of the crash involved truck is to associate the individual vehicle with a firm and then to reference some database indicating the primary operations type for the whole firm. The TTS Blue Book database of 2,681 motor carriers provides two key indicators for specifying operations type, and also provides the USDOT motor carrier identification number for these carriers. Average length of haul for trips made in the year and the freight revenues from long and short distance transportation are reported in the database. The average length of trip variable can be used directly to classify carriers. A calculated proportion of revenue derived from short distance operations could also be used to classify carriers. There are 2,481 firms in the TTS database with sufficient information to be able to classify them as long or short haul. With these data, the motor carrier identification number can be used to match firm records to the MCMIS and (to a lesser extent) FARS crash files. There were 32,342 different firms with a fatal, injury or property damage only crash reported in the MCMIS database during 2000, so the TTS data alone cannot provide a very good match for ascertaining operations type. The 2,481 firms with data can account for 2,016 matched crash records in the year 2000.

[111] For the Preliminary RIA, a similar adjustment for the effects of fatigue on inattention was used in estimating the percentage of crashes caused by fatigue. In that analysis, however, it was assumed that inattention contributed to 50 percent of crashes, on the basis of a small sample of in-depth crash assessments. This adjustment, which added 20% times 50%, or 10 percentage points to the estimate of the percentage of fatigue-related crashes, is the main source of the difference between the previous estimate of 15 percent and the estimate of 8.15% shown in Exhibit 8.2.

Another possible criterion for establishing the operations of a motor carrier is the primary commodity being carried. The Blue Book database has one field for each carrier indicating the commodity hauled. The TTS National Motor Carrier Directory lists the top four commodities being carried, while the MCMIS motor carrier census lists up to 30 different commodities that each firm may carry. There are a number of commodities that are very clearly associated with short haul carriage (cement, garbage, tank petroleum products, coal/coke, ores, grain, livestock, et al). These products are associated with special equipment used (as mentioned above), are hauled by train when moving long distances or have some other characteristic that makes long distance carriage untenable or uneconomical. The relative number of long and short haul firms carrying any one of the 24 different commodity groups in the Blue Book data provides a very good benchmark for the potential classification of data in the motor carrier census. A discriminant analysis of the Blue Book data revealed that a substantial number of firms could be classified as long or short haul based on the primary commodity that they carry. Petroleum tank products, dump trucks, agricultural commodities, film products and local cartage operations are predominantly listed by firms otherwise classified as short haul. Firms handling refrigerated solids, refrigerated liquids and household goods were primarily classified as long haul.

A final set of characteristics could be used to classify carriers by long and short haul operations. The number of power units owned or leased or number of drivers employed divided by the total miles driven per year provides a measure of the utilization rate of these resources. Other data from the Blue Book indicate that the low mileage per power unit (or driver) firms tend to be involved in short haul carriage. Low end and high end cut-off points were established for these variables and the carriers at the extremes were classified according to these utilization variables. Since mileage, drivers, and equipment details are available for a large proportion of the firms listed in the USDOT motor carrier census, this analysis was conducted for all 889,381 carriers in the database. Based on a review of the Blue Book data, a logical cut-off point of 30,000 or fewer miles per year per driver or power unit was established for defining short haul trucking firms and a cut-off point of 60,000 or more miles per year per driver or power unit was established for defining long haul trucking firms. Firms with average driver and vehicle usage between 30,000 and 60,000 miles per year were left unclassified.

The results of these three analyses were combined to develop the overall estimates of short and long haul involvement in the 103,055 truck crashes in the 2000 MCMIS Crash database. The crash data cargo body criterion was given the highest priority in the classification, followed by the Blue Book average trip length, chief commodity, and utilization, finally incorporating the MCMIS Census file commodity and utilization information. Once a crash was classified by one of these methods the methods following it in the priority list were not used. For the MCMIS commodity and utilization tests, consistency checks were used to assure that there was no conflict in classification using the different methods. If a conflict was detected, then the carrier was left unclassified. Approximately 70% of the fatal crashes, and 65% of the injury and property damage only crashes could be classified as long or short haul using this procedure.

Exhibit 8-3 shows the numbers and proportion of crashes in calendar year 2000 broken out by long- or short-haul firms. The raw percentages have been adjusted to reflect the relative involvement of long and short haul operations noted. This allocation scheme assumes that the unclassified crashes should be distributed proportionally to the long and short haul groups. For 2000, there was an approximate 60% to 40% split between long and short haul operations involvement in fatal and property damage only crashes. Long haul operations were associated with approximately 55% of the injury only crashes. These estimates can be used with the baseline crash numbers derived from FARS and GES to establish the historical baseline of crash involvement for the two different types of motor carrier operations. From that we can estimate the relative benefits of crash reduction due to differing hours of service proposals.

Exhibit 8-3
Division of Crashes by Length of Haul

	Fatal	Injury Only	PDO
Long Haul	1,961	17,327	18,890
raw %	42.9%	36.0%	37.5%
Adjusted %	**61.8%**	**55.0%**	**59.0%**
Short Haul	1,210	14,169	13,118
raw %	26.5%	29.4%	26.1%
Adjusted %	**38.2%**	**45.0%**	**41.0%**
Unclassified	1,398	16,646	18,336
raw %	30.6%	34.6%	36.4%
Total	4,569	48,142	50,344

Source: MCMIS Crash Data, 2000, and Jack Faucett calculations.

8.3 Sleep Models

Sleep models are used to analyze the major processes underlying sleep regulation. They also provide a conceptual framework for the analysis of sleep data. As pointed out in the sleep literature, sleep regulation involves three processes: (1) the homeostatic process[112] which increases during wakefulness and decreases during sleep; (2) the circadian process which depends on the circadian oscillator controlling temperature and alertness rhythms; and (3) the ultradian process which determines the NREM/REM (Non Rapid/Rapid Eye Movement) periodicity.[113]

Over the past two decades, quantitative models have been developed to describe human sleep regulation. Most current mathematical models of alertness include a homeostatic component and circadian component.[114] Sleep models also account for the regulation of the alternation between non-REM sleep and REM sleep. In one class of models, an ultradian oscillator regulates the alternation of non-REM and REM sleep. In the second class of models the alternation between non-REM sleep and REM sleep is governed by homeostatic processes related to non-REM sleep and REM sleep itself.[115]

[112] The homeostatic process is often referred to as Process S. The homeostatic process triggers an increase in the demand for sleep after a period of prior wakefulness. It reflects the extent to which the need for sleep has been satisfied.

[113] Borbely A.A., Achermann P. (1992), "Concepts and Models of Sleep Regulation: An overview", *Journal of Sleep Research,* 1(1), pg. 63

[114] Jewett ME, Dijk D-J, Kronauer RE, Czeisler CA. (1996), "Homeostatic and circadian components of subjective alertness interact in a non-additive manner", *Journal of Sleep Research 1996; 25: 555.*

[115] Dijk D-J, Czeisler CA., "Bimodal distribution of REM sleep latency during forced desynchrony: model implications", *Journal of Sleep Research 1996; 25: 122.*

8.3.1 Variation Between Models

Sleep models differ on how the various components interact with each other. Some models assume an additive interaction between the circadian and homeostatic components of alertness while later studies provide evidence of a nonadditive interaction.[116] Jewett et al (1999)[117] developed mathematical models in which levels of subjective alertness and cognitive throughput are predicted by three components that interact with one another in a nonlinear manner. These components are: (1) a homeostatic component (H) that falls in a s-shaped manner during wake and increases at a decreasing rate that asymptotically approaches a maximum during sleep; (2) a circadian component (C); and (3) a sleep inertia component (W) that increases at a decreasing rate after awakening.

Sleep models also vary depending on the model's purpose. More recently, efforts have been made to develop sleep models that can quantify the relationship between sleep, circadian rhythm and performance. The models use sleep data as input and they yield predicted alertness as well as performance on monotonous tasks. Some models include an identification of levels at which the risk of performance or alertness impairment starts, as well as prediction of sleep latency and time of awakening of sleep episodes. Examples of this new generation of sleep models include the following: the Fatigue Audit InterDyne model (FAID), the Circadian Alertness Simulator (CAS) and the Walter Reed Sleep Performance Model (WRAIR-SPM). The features, functions, and applicability of the WRAIR-SPM will be described in the next section while the description of the other comparable sleep models can be found in Appendix E.

8.3.2 Walter Reed Sleep Performance Model

The Walter Reed Sleep and Performance Prediction Model (WRAIR-SPM) was conceived in the late 1980s by Colonel Gregory L. Belenky, US Army, and members of his research staff at the U.S. Army's Walter Reed Army Institute of Research (WRAIR). The WRAIR-SPM is a quantitative model that was initially designed to predict the performance of soldiers during extended operations.

During the 1990's, WRAIR's sleep researchers refined the model based on data obtained from studies of sleep loss per se as a determinant of cognitive performance. They focused on the effects of total and partial sleep deprivation on a wide range of psychological and cognitive performance tests. The cognitive task performances selected from the WRAIR Performance Assessment Battery (PAB) include those that tap into brain functions representative of those involved in doing military command and control tasks (e.g., serial addition/subtraction, logical reasoning, choice reaction time and pattern recognition tasks).

Further attempts to refine the model in the mid-1990s led to debates about whether expected performance decline during complete sleep deprivation periods were linear, or degraded in a step-wise function over time for successive days of military operations. The step-wise cognitive

[116] Dijk, DJ. et al. "Circadian and sleep/wake dependent aspects of subjective alertness and cognitive performance", *Journal of Sleep Research 1992, 1:112117.*

[117] Jewett, M.E., Kronauer, RE., (1999). Interactive mathematical models of subjective alertness and cognitive throughput in humans, Journal of Biological Rhythms 1999;14(6):588-97.

performance degradation function (Angus & Heslegrave, 1985)[118] indicates that performance was relatively constant until about 18 hours of non-stop work which is similar but not the same as time-on-task). After 18 hours of non-stop work, performance drops by 25% from baseline, and remains at a constant level until about 30 hours of continuous work. At this point, it drops by another 15-20%, and subsequently begins to deteriorate to 30% of baseline over three days in sustained performance tasks.

In order to extend and validate the parameters of the WRAIR-SPM, the FMCSA and other government agencies sponsored a large-scale laboratory confinement study to determine the effects of four sleep/wake schedules on alertness and performance. The Sleep Dose-Response study (SDR) examined the effects of one week's restricted sleep (three, five, seven, or nine hrs per night) on the performance of 66 CMV driver subjects. Multiple measures of performance, including psychomotor vigilance tasks (PVTs) and driving performance measures, were taken while drivers did a sequence of 45-minute drives on a low-fidelity desk-top truck driving simulator (Balkin, et al., May 2000). This study resulted in numerical estimation of parameters for the WRAIR Sleep Performance Model, and elucidated the relationships among several sleep-related performance measures.

Prior to the sleep dose-response (SDR) simulator study by Balkin et al., Belenky and the WRAIR team originally based their prediction model (originally called SPM-96 and framed around only young healthy males) on its ability to predict a person's performance on the serial addition/subtraction task from the WRAIR-PAB (Thorne et al., 1985)[119]. The SDR truck simulator study added experience with a more diverse population of subjects. With this information, they refined the WRAIR-SPM model and they began to base the prediction algorithms around the Dinges Psychomotor Vigilance Task, a simple reaction time test (Balkin et al., 2000). Generally, the PVT reaction time scores are used as indications of a secondary task measurement to indicate the level of "alertness" remaining, the reservoir of alertness still there in the subject while being subjected to a long or arduous work stint, e.g. continuous performance demands over time.

After the SDR study with truck drivers in the simulator, the WR-SPM gradually became a four-process model. Essentially, the timing and duration of a person's sleep and wakefulness periods over several days constitutes an individual's sleep/wake history. Four separate functions are used to relate sleep/wake history to level of cognitive performance capacity, including (a) a wake function, (b) a sleep function, (c) a "delay of recuperation" function, and (d) a sleep inertia function.

Because the parameter values for the latest WRAIR-SPM were estimated using normalized Response Time on the Psychomotor Vigilance Task as the performance metric, and given the wide acceptability of PVTs as a "standard" by which many sleep deprivation and performance studies are measured, the next section will be devoted to describing the main features of the psychomotor vigilance task.

[118] Angus, R.G. & Heslegrave, R.J. (1985). Effects of sleep loss on sustained cognitive performance during a command and control simulation. Behavior Research Methods, Instruments, & Computers, Vol. 17, No.1, pp 55-67.

[119] Thorne, D. R., Genser, S. G., Sing, H.C. & Hegge, F.W. (1985). The Walter Reed performance assessment battery. Neurobehavioral Toxicology and Teratology, Vol. 7, pp 415-418.

8.3.3 Psychomotor Vigilance Task

The Psychomotor Vigilance Task is a test of behavioral alertness developed by David Dinges, Ph.D. and John Powell, M.A. in the mid-1980s at the University of Pennsylvania (UPENN) Hospital. The PVT was designed to evaluate the ability to sustain attention and respond in a timely manner to salient signals (Dinges & Powell, 1985).[120] It was also designed to be free of a learning curve or influence from acquired skills (e.g. aptitude, education), and to be highly sensitive to an attentional process that is fundamental to normal behavioral alertness.

PVT performance has been demonstrated to be highly sensitive to detecting changes in behavioral alertness associated with numerous work settings (e.g. medical house staff jobs, night shift workers, drowsy drivers, transoceanic pilots). PVT performance is also sensitive to bodily states (e.g. partial and total sleep-deprived subjects, truck drivers with sleep apnea, sleepy elderly subjects), and to exposure to various ingested chemical substances (e.g. caffeine, modafinil, and alcohol).

In the study of operating practices in a high-fidelity truck simulator, O'Neill et al. (1999)[121] examined two weeks of day-time driving (0700-2130 hrs) that entailed simulated driving tests of 12 hours per day on a 14 hours on duty and 10 hours off duty work schedule. Ten-minute PVT tests were administered three times per day (at 0645, 1330 and 2100 hrs) during a five-day driving workweek, and four times per day on the drivers' weekend off recovery days (0900, 1300, 1700 and 2100 hrs). PVT data were reported in the form of median and mean reciprocal response times, and number of lapses, combined on a graph. The authors found that PVT scores were sensitive to partial and full sleep deprivation, thus underscoring the value of properly designed work-rest schedules.

The PVT is acknowledged as being one of the most consistently reliable research tools for the study of operator alertness, fatigue and/or drowsiness. The PVT test of simple choice reaction time is backed by almost two decades of experience and historical data. It has been used widely by the research community in many studies e.g. Balkin, (2000)[122]; O'Neill et al. (1999); Hartley et al., (2000)[123] and Krueger, (2002).[124]

Model Calibration

Balkin et al. (2000) described the WRAIR-SPM as "a series of empirically derived mathematical relationships describing the continuous decrement of cognitive performance during wakefulness,

[120] Dinges, D.F. & Powell, J.W. (1985). Microcomputer analyses of performance on a portable, simple reaction time task during sustained operations. Behavior Research Methods, Instruments & Computers, Vol. 17, No. 6, 652-655.

[121] O'Neill, Krueger, G.P., Van Hemel, S.B., & McGowan, A.L. (1999). Effects of operating practices on commercial driver alertness. (FHWA-OMC Technical Report No. FHWA-MC-99-140.)

[122] Balkin et al. Effects of sleep schedules on commercial motor vehicle driver performance. Washington, DC: US Dept. of Transportation, Federal Motor Carrier Safety Administration, Report No. DOT-MC-00-133, May 2000.

[123] Hartley, L., Horberry, T., Mabbott, N. & Krueger, G.P. (2000). Review of fatigue detection and prediction technologies._ Melbourne, Australia: Australian National Road Transport Commission Technical Report, Sept. 2000.

[124] Krueger G.P, & Van Hemel, S.B. (2001). Effects of loading and unloading cargo on commercial truck driver alertness and performance._ Federal Motor Carrier Safety Administration FMCSA Technical Report No. DOT-MC-01-107 (May 2001).

restoration of cognitive performance during sleep, and cyclic variation in cognitive performance during the course of the day."

Wakefulness was assumed to diminish cognitive performance capacity by a simple linear decay function $Ct = Ct\text{-}1 - \kappa w$, where Ct is the cognitive performance capacity at time t, and κw is the performance depletion occurring in the interval t-1 to t.

Sleep was assumed to restore cognitive capacity utilizing an exponential growth function. For a subject going to sleep once cognitive capacity reached zero and remaining asleep for a period of time t, cognitive capacity would equal 100 * (1 - e-c2*t).[125] In this representation, the coefficient c2 is the sleep recovery time constant.

The third component of the model is the circadian phase modulating function (M) which has both a circadian (24-hour) and ultradian (12-hour) component. To reflect the 24-hour circadian and 12-hour ultradian components, M is expressed as an additive double cosine function:

$$M = 1 + c_3 * \cos((2\pi / 24) * t + c_4) + c_5 * \cos((2\pi / 12) * t + c_6)$$ [126]

where c3 and c5 represent the amplitude parameters for the cosine functions c4 and c6 represent phase shift parameters from midnight (the beginning of a day). In the WRAIR-SPM, predicted performance at a given time (t) is expressed as the product of the Current Cognitive Capacity (C) and the Modulating function (M).

Inputs

The microcomputer software model enables users to enter sleep/wake schedules in which the subject follows the exact same pattern over a period, or to enter a schedule where the subject's sleep pattern varies from day-to-day. The model has the capacity to evaluate schedules that cover up to 100 days. The following are the major input components to the WRAIR-SPM model.

Sleep/Wake History

The first major input to the model is sleep/wake history. The sleep/wake history represents the timing and duration of sleep and wakefulness periods over a period of days. In the WRAIR-SPM, four functions are used to relate sleep/wake history to cognitive performance capacity level (CPCL). These four functions, and a brief description of their relationship to cognitive performance are as follows:

- Wake/Decrement Function – The wake/decrement function describes how cognitive performance declines during periods of continuous wakefulness.
- Sleep/Restoration Function – The sleep/restoration function describes the rate at which cognitive performance capacity accrues during sleep.

[125] FMCSA, "The effects of sleep schedules on commercial motor vehicle driver performance", May 2000. pg. 3-9.

[126] FMCSA, "The effects of sleep schedules on commercial motor vehicle driver performance", May 2000. pg. 3-9.

- Delay-of-Recuperation Function – The delay-of-recuperation function was incorporated into the model to exhibit the time lag between the wake/decrement function and the sleep/restoration function at the beginning of sleep. This delay is set at five minutes in the model, the time assumed to transition into recuperative sleep.

- Sleep Inertia Function – The sleep inertia function accounts for the gradual restoration of normal performance and alertness upon awakening (approximately 20 minutes).

Time of Day (Circadian Phase)

The second input is the circadian phase, which is based on time of day. This component accounts for the empirical data showing that CPCL oscillates between a five and twenty percent peak to trough over a 24-hour period. Reflecting the influence of circadian and ultradian rhythms on performance, performance is lowest in early morning hours, and increases across the day (except for a dip in the afternoon), and peaks in the evening hours, prior to sleep onset.

Output

Based on the user input of a sleep/wake schedule, the model will generate graphical and tabular outputs. The tabular data presents minute-by-minute reports of the subject's sleep/wake status at the particular time and level of predicted performance. The level of predicted performance is reported numerically on a scale ranging from zero (0) to one hundred (100).

Model Limitations

The model does not differentiate between "awake and working" versus "awake and resting" times. Conceptually, one might think that the former would take a greater toll on one's performance level capacity for subsequent periods in the day as compared to the latter. In addition, it does not explicitly take into account the interaction of physical and mental exhaustion and it does not recognize any time-on-task effects separate from the general cognitive depletion and circadian functions.

Application to Current Research Effort

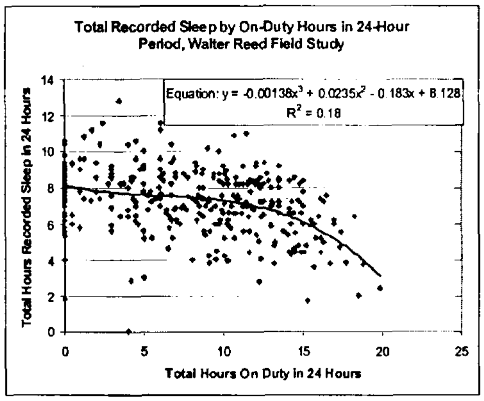
Unlike proprietary products, the detailed information needed to evaluate alternative scheduling options under this study is readily available and easy to modify and replicate. These features make it the best tool for the evaluation of the HOS alternatives considered for this study. For analytical convenience, especially entering data and obtaining output from the model, the equations behind the WRAIR-SPM were implemented in a spreadsheet, fully described in Appendix G.

8.4 Estimating Sleep Profiles

The modeling uses actigraph data from the Walter Reed field study to predict sleep in a 24-hour period based on time on duty in 24 hours. The Walter Reed field study provides the most accurate measure of actual sleep (rather than reported sleep) as well as its relationship to time worked. Because the dataset follows a panel of people across time, the appropriate model is a random-effects cross-sectional time series model for panel datasets.[127] Diagnostic tests indicate the appropriateness of a random effects model.[128]

The data suggests the most appropriate functional form is a cubic regression equation (third-order polynomial), particularly given the interest in accurately reflecting hours of sleep for those working longer hours.[129] This relationship between time sleeping and time on-duty is then used to predict sleep given modeled numbers of hours on duty.[130] (See Exhibits 8-4 and 8-5.)

Exhibit 8-4
Relationship of Sleep to Time Off



Source: Walter Reed Field Study and ICF Analysis.

[127] Theory suggests that the individual differences are random disturbances drawn from some general distribution rather than that each person has a fixed effect shifting the equation up or down. That is, we do not expect a higher or lower level of residuals by individual. In order to run the model appropriately, we assume all days are sequential even if one day's observation was missing or was dropped due data problems. There is an extensive literature on longitudinal models. For a good discussion about fixed and random effects models see William Greene, *Econometric Analysis*, Macmillan Publishing, 1993, Ch 16 section 4.

[128] A Hausman test did not reject the null model that the fixed and random effects model are equivalent at a 5 percent alpha level, although it did at a 10 percent level. The coefficients and standard errors found using the random effects model, however, differ only slightly from either using a fixed effects model or pooling the dataset (coefficients only) as if the data points were all independent individuals. This indicates that mispecification is not likely to have affected results. For instance, the fixed effect regression equation results in predictions for sleep vary by no more than five minutes from the random effects model.

[129] The data show clear non-linear tendencies, and a quadratic equation provides predictions that fall out of the realm of that possible (more than 24 hours of activity per day) for people who report a large number of hours on duty. Because of the interest in this study of accurately reflecting schedules for people who work a large number of ours, we use a cubic functional form that more closely matches the data especially if a driver is modeled as having worked a large number of hours. The equation estimated is $y = 8.12800 - 0.18272\ x + 0.02335x^2 - 0.00138x^3$. The R-square is reasonable given the number of data points available.

[130] We attempted to compare the relationship between hours of sleep and time on-duty found from the Walter Reed Field Study with that found from the two waves of the UMTIP data. We expected the relationship to be larger for UMTIP because it provides self-reported time sleeping rather than actiwatch monitoring of actual sleep. Another qualification is that the UMTIP did not require drivers to verify time on duty by logging on duty periods or referring to their log books. Because there were problems with the accuracy of the UMTIP data (see Appendix B), we use the UMTIP data only as a check on the magnitude of predicted difference in hours slept due to different hours on duty. The slope of the regression equation using the UMTIP data produces less reliable estimates, rising from eight hours of sleep in the last 24 with zero hours on duty to over 9.5 hours of sleep when working six hours in the last 24. The downward slope for hours worked above ten was somewhat steeper than that resulting from the Walter Reed data.

Exhibit 8-5
Predicted Hours of Sleep in 24-Hour Period by Selected Hours On Duty

Hours On Duty	Predicted Hours Sleep
0	8.13
6	7.57
8	7.45
10	7.25
12	6.91
14	6.35
16	5.52
18	4.34
20	2.75

Source: Walter Reed Field Study and ICF analysis.

8.5 Estimating Change in Short-Haul Crashes using Model Schedules

We model daily schedules for short-haul drivers to input into the Sleep Performance spreadsheet (described in Appendix G) to predict differences in incremental crash risks for a baseline with full nights of sleep, actual compliance with current HOS rules, current HOS rules under full compliance, and the three proposed options. Research on schedules for short-haul drivers is more limited than for long-haul drivers. The literature indicates that these schedules are noted for their more regular pattern of work even if length of the work day varies. This section describes how we model daily patterns for short-haul drivers, vary them using the schedules developed in section 5.2, and input them into the Sleep Performance spreadsheet to measure crash risk increment from the proposals.

We model daily schedules for short-haul drivers using information on typical short-haul schedules from the Virginia Tech Field Study and Virginia Tech Focus Groups. We confirmed general lessons from these sources with industry representatives involved in short-haul operations.[131] Column 2 of Virginia Tech Focus Groups' Table 4 (p. 8) outlines typical daily patterns for local beverage truck drivers. The general pattern begins with an early start to the work-day beginning with pre-trip inspections and paperwork. The trip to the first delivery stop is about 15 to 30 miles followed by delivery and paperwork activities. This is followed by a series of shorter driving times (about three miles according to the table) among subsequent route stops and delivery and paperwork activities of roughly constant length. The route ends with a trip back to the facility followed by assisting in reloading or paperwork. The Virginia Tech Focus Groups' Table 14 (p. 77) lists average number of deliveries for beverage and snack delivery drivers as just over 11 per day. Figure 25 in the Virginia Tech Focus Groups (p. 75) indicates

[131] Table 4 from the Virginia Tech Focus Group is reproduced in Appendix J. We did not encounter other descriptions in the literature of typical driving/working patterns for short-haul drivers. Industry representatives contacted indicated that delivery patterns for other types of short-haul drivers vary only moderately from this pattern. These differences should not create relative differences among options, however, and calibration at the end of the process should offset these differences.

that the average short-haul driver in the focus groups spent 29 percent of their non-break time driving.[132]

All short-haul drivers are modeled as arriving at work at 7:00 am, the median response to time of day they start work.[133] They are modeled as having awoken a half-hour before arriving at work. Sensitivity tests indicated that modeling the drivers as arriving at work 75 minutes after awakening made minimal differences among the proposals.[134] Following the information discussed above, short-haul drivers are modeled as performing non-driving work for their first half hour on duty, followed by a half hour of driving to arrive at their first delivery stop and a half-hour of non-driving work at the first stop.[135] Drivers' last half hour is modeled as non-driving work. For the remaining hours on-duty for short-haul drivers, time is modeled as a repeating pattern of alternating deliveries such that even numbered deliveries begins with a quarter-hour of driving followed by three-quarters of an hour of non-driving work and odd deliveries begins with a quarter-hour of driving followed by a half-hour of non-driving work. These lengths were chosen such that short-haul drivers drive just over 30 percent of the day for average workdays of 10.3 hours in length.[136] Because we are interested primarily in the differences in crash risk among the proposals, the exact number of deliveries or length of time spent on each aspect of a driver's duties is less important than the even distribution of driving throughout the day.

This general pattern of daily schedules is applied to the 25-day schedules developed in Section 5.2.[137] The series of schedules are adapted such that the short-haul drivers do not work on the sixth and seventh day of the week to reflect the typical regular work week schedules found in the industry.[138] For a given night, the amount of sleep is modeled based on the calculated relationship between sleep and time on-duty discussed in section 8.4.[139] We model sleep for short-haul drivers as ending a half-hour before leaving for work. The time sleep begins varies according to the amount of total time (within a quarter hour) of estimated sleep. We then input a 25-day working schedule developed in section 5.2 from every fourth driver into the Sleep Performance spreadsheet for each of the proposal options as well as for the current compliance

[132] This indicates that the driving hours limitations in the PATT proposal and the FMCSA proposal should not constrain short-haul drivers. This average response of 29 percent of a work-day spent driving is somewhat less than that suggested by the Virginia Tech Field Study question asking "What percentage of work time is driving?" The modal response in the field study was 50% (answers were restricted to <50%, 50%, >50%, 100%.)

[133] We do not have data on the amount of time between awakening and arriving at work for short-haul drivers.

[134] Modeling arrival time this way slightly overestimates the benefits of the ATA proposal relative to current full compliance, PATT, and FMCSA. The difference in actual benefits, however, would be minimal.

[135] These time lengths were based partially on the approximate number of miles driving for each segment in Appendix J divided by 20 mph speeds in city between deliveries and by 40 mph from the terminal to the first stop.

[136] This is the average length of work day according to the Virginia Tech Field Study and the average length of work day modeled under current compliance levels. The Virginia Tech Focus Group drivers provide a slightly longer average shift length of 10.89 hours.

[137] This is done by inputting the daily driving schedule pattern as an equation conditional on length of day and varying the 25-day schedule as an input.

[138] Representatives involved in the short-haul industry indicated that most short-haul operations are based on a regular five-day work week. Similarly, the majority of local pick-up and delivery respondents in the UMTIP survey

level. The schedules for each proposal vary only by the threshold at which individual work days are truncated.[140] The resulting incremental crash incidence calculation for each scenario is subtracted from a baseline crash increment. This baseline increment represents the model's estimated crash risk increment from five-day work week schedules of 8 hours of sleep with driving spread throughout the day.[141] Given the assumptions in our baseline, the model provides a baseline crash increment of −1.72 percent, just slightly below the 0 percent expected theoretically. Because this baseline is subtracted from the increment for each proposal, its size does not affect the results, which are presented at the end of the following section.

8.6 Modeling Schedules: Long-Haul Driver Schedules

Modeling schedules of long-haul drivers to find the percentage of crashes that are fatigue-related for each proposal involves many steps, which we address in separate sub-sections. Because of the large number and complicated nature of these procedures, this section describes each step only briefly. Step-by-step details, calculations, and tables and figures are provided in Appendix F. The order of the sections in the appendix are parallel to those found here. First, as described below in section 8.6.1, we gather data on the distribution of schedule types – including hours worked per day, number of days per work week, shifting of sleep times, and other relevant information by driver types. Section 8.6.2 describes our calculations to account for the effects on schedule rotation for long-haul drivers working heavy schedules. In section 8.6.3, we discuss creating sample driver schedules that can apply to the various driver types. These schedules are input into the Sleep Performance spreadsheet based on the WRAIR-SPM. Section 8.6.4 presents the results from running each driver schedule through the Sleep/Performance to calculate incremental crash risk for each HOS rule option. In section 8.6.5 we weight crash risk increments to appropriately reflect the distribution of driver schedules expected under each proposal. An interim crash risk increment for each proposal is calculated from this weighting process; the interim crash increment for each option is subtracted from the baseline crash increment, and adjusted to match productivity levels used in the cost estimates. We calculate the proportion of truck crashes in which fatigue may have played a role, and from this the percentage of all crashes that are fatigue-related. This section discusses these steps. In a later section, these modeling results are calibrated to the independent assessment of the incremental crash risk from truckers in general and the proportion of crashes estimated to be from long-haul drivers.

8.6.1 Distribution of Driver Schedule Types

The first step to finding the percentage of crashes that are fatigue-related for each option is determining the distribution of driver schedule types. This includes hours worked per day, number of days worked, shifting of sleep times, and other relevant information by driver types. We gather descriptive statistics describing the distribution of schedule types from UMTIP and the Walter Reed Field Study in order to model 25-day schedules representative of those found in the real world.

[140] Additional drivers are not modeled explicitly under the simplifying assumption that replacement drivers will work and drive similar day lengths as the dataset average.

[141] Driving is spread throughout the day in order to get an appropriate baseline that reflects an average of any time of day driving.

In order to model representative schedules, we estimate the distribution across 100 model drivers of average number of hours worked per day We group these schedules into four bins representing average work day lengths around nine, 11, 13, and 15 hours on-duty on average in a 24-hour period (excluding full days off-duty). These bin values are chosen to divide the distribution such that the middle two values (11 and 13) represent about a third of the distribution under current compliance levels, with the remainder divided about equally between the other two values. This provides the average number of hours worked per 24-hour period worked for the current HOS rules under current compliance (status quo scenario).

Next, we move from average number of hours worked per 24-hour period to number of hours worked per eight day work period under the current HOS rules. From UMTIP, we use a frequency distribution of number of days worked in the last seven-day pay period. Interviews with industry experts indicate that most OTR long-haul drivers follow an eight-day work schedule. In order to make this distribution based on seven-days apply to the current compliance baseline, we scale up the UMTIP distribution from days worked in seven to days worked in eight days. The majority of drivers in the resulting distribution worked five to eight of the last eight days. Those who work four or fewer days in eight are not expected to be affected by changes in HOS rules. We therefore simplify the analysis and reduce the number of schedules to model by combining into one bin those who worked four or fewer days within the eight-day period. Exhibit 8-6 displays the original distribution of work week lengths as well as the rescaled and simplified distributions.

Exhibit 8-6
LH Work Week Length for UMTIP and Modeled Drivers

	# Days per Week							
Driver Distribution	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
UMTIP 7-Day Distribution	1%	3%	5%	13%	35%	24%	21%	0
Distribution Rescaled to 8 Days	0%	1%	3%	7%	19%	31%	23%	15%
Simplified Distribution	0%	0%	12%	0%	19%	31%	23%	15%

Source: UMTIP and ICF Analysis

No information is available in the UMTIP survey to estimate directly the proportion of the driver population by both hours worked in 24 hours and the number of days worked; therefore, we multiply together directly the proportions we found in the two previous steps. That is, we multiply the proportion who worked on average around nine, 11, 13, or 15 hours in 24-hours by the proportion who worked three, five, six, seven, or eight days in an eight-day schedule. For clarity, in the following paragraphs, we refer to the resulting matrix of proportions of truckers working various hours-per-day and days-per-eight as the "driver schedule proportion matrix" and any individual cell within the matrix a "driver proportion cell."

The driver schedule proportion matrix is generated first to reflect current compliance levels with HOS rules.[142] The proportion matrix must be adjusted for each HOS option because different numbers of hours worked per week are allowable under each proposal. We first truncate driver proportion cells to reflect daily and weekly limits allowed under current HOS rules. That is, if a

[142] The degree of compliance for long-haul drivers is inferred using two different data elements from the UMTIP survey.

group of drivers work too many hours per day or week, we add the proportion of drivers in that cell into a permissible cell. We repeat this truncation for each proposed HOS option. A description of this process is found in Appendix F, section 1.

8.6.2 Rolling Work/Sleep Schedules

Next, we used the modeled runs from the dispatching simulation, discussed in Section 5-1, to predict the extent to which, under the HOS rule options, drivers' primary sleeping time (and, thus, their whole sleep-work cycle) steadily moves, or rolls, over a series of days or remains fixed over time. As discussed earlier, the proposed rule options are likely to have different effects on schedules given their working and driving time limits in a 24-hour period.

For the current rule as followed in the real world, survey data indicates that about half the drivers currently find the time of their primary sleeping bout to shift over nights. We analyzed the likelihood of rolling separately for each proposal and for regional and long-haul operations. We also measure separately the number of hours a schedule rolls in order to down-weight schedules that roll for fewer hours than modeled. A detailed description of how we determine the proportion of schedules that roll as well as results of this process is available in Appendix F, section 2.

For the current rule fully enforced, the result is a weighted average of 34 percent of drivers rolling backwards an average of 10 hours (given a five-day route). For the PATT rule, the result is a weighted average of 8 percent of drivers rolling backwards an average of 10 hours. For the FMCSA proposal, the result is a weighted average of 13 percent of drivers rolling backwards an average of 10 hours. For the ATA proposal, the result is a weighted average of 54 percent of drivers rolling forwards an average of 10 hours.

8.6.3 Creating Sample LH Driver Schedules as Spreadsheet Inputs

In this section, we set up model schedules representing drivers from each driver proportion cell for input into the Sleep/Performance spreadsheet. Two types of schedules are modeled – those in which the work-sleep cycle continues to shift over a series of days and those in which they remain fixed over time. Schedules that roll both backward and forward are modeled.

Non-Rolling Schedules

We model each non-rolling work schedule as beginning with a sleep period centered at 11 pm – around the ideal time for a driver's circadian rhythm.[143] This is followed by an hour for the driver to wake and eat and then the appropriate number of hours on-duty for that driver cell (9, 11, 13, or 15 hours). The exception to this set of non-rolling schedules is for the ATA proposal. For schedules for which drivers work 13 to 15 hours, we model their seven-day schedules as five or 4.66 days long to serve as even comparisons for the forward rolling schedules discussed in paragraphs that follow. The first hour for all modeled schedules is non-driving work. This is

[143] For simplification, we do not model naps during the day. Preliminary analysis indicates that doing so produces only minor differences in results from modeling total sleep time as occurring all at night. (Because the Walter Reed Field Study data is based on total sleep in 24 hours, modeling naps would be equivalent to moving sleep from a single sleep bout to two bouts.) For 1.5 hours of nap time at 3 pm every third day, which represents the average found in the Crum data set, there is an additional 1.2 percent raw crash increment before calibration.

followed by a regular pattern of four hours of driving and a one-hour break until a threshold number of driving hours is reached. After the threshold of driving hours is reached, the workday continues with any additional non-driving work time until the total number of hours of work is reached.[144] Sleep after workdays also is centered at the ideal time for circadian rhythms. Drivers are modeled as working three, five, six, seven, or eight days per eight-day period. For days during which the driver is not modeled to work, sleep time is modeled as 8.25 hours the day off, and no driving time is modeled. Examples of modeled driver schedules are provided in Appendix F, section 3.

Rolling Schedules

In accord with *a priori* expectations and the findings for the current compliance scenario, we model schedules with sleeping periods that roll backwards as rolling two hours per night. For simplicity, we model only one set of schedules rolling backwards. Rolling schedules also all begin at 11 pm with a sleep period centered around the ideal time for a driver's circadian rhythm. Modeled sleep periods are followed by an hour for the driver to wake and eat and then the appropriate number of hours on-duty for that driver cell.

Schedules that shift by two hours are complicated by having combined sleep-work cycle lengths of 22 hours (that is, 24 minus 2 hours). The calculations involved in modeling sleep and driving time in rolling schedules are provided in Appendix F, section 3.

As with the non-rolling schedules, drivers are modeled as working three, five, six, seven, or eight days per eight day period. Schedules continue to roll backwards until the end of work week, when drivers return to a normal sleep schedule. As with the non-rolling schedules, work hours follow a regular pattern of four hours of driving followed by a one-hour break until a threshold number of driving hours is reached. The seventh and eighth nights of sleep are off-duty, and therefore are 8.25 hours long followed by no hours driving those days.

ATA Schedules

The modeling approach was similar for the ATA option in terms of back-calculating the number of hours driving and sleeping. For those driver cells for which people currently are working well below the ATA daily limits – those working on average nine or 11 hours per 24-hours – we would not expect forward rolling cycles. We model these drivers using the same schedules as those rolling backwards.

We also would expect some truckers under the ATA option to have schedules intense enough that they expect their sleep-work cycles to roll forward. We model this as occurring for drivers working on average 13 or 15 hours per 24-hours. In those cases, a driver can work only about five sleep-work cycles before one reaches 70 hours at 13 hours per cycle or 4.67 cycles if working 15 hours per cycle. For these drivers, we model schedules of 3 or 4.66 cycles for those

[144] Another difference between the ATA and other schedules is that we model an extra two hours of driving time only for long-haul (not regional) truckers under ATA in line with our Route Pro modeling. They are able to drive these extra two hours because ATA does not distinguish between driving and non-driving hours and because long-haul drivers will spend less time in loading and waiting activities than regional drivers.

averaging 15 hours of work per cycle and 3 or 5 cycles for those averaging 15 hours of work per cycle.

For ATA, we distinguish between drivers who work for regional and those working for long-distance haulers to account for the differences in amount of time driving versus other non-driving work (such as loading and hooking) for these two categories of over-the-road drivers. A final distinction we make among schedules under the ATA option is to model differently those who work a large number of hours per week. This extra productivity allowed under the ATA rules is reflected in the Route Pro runs and in the cost analysis. We therefore reflect this productivity in the benefits analysis. At the end of the cycle, we model the drivers who work less than 90 hours as having the time to reset their sleep schedule by not working the remainder of the seven-day period and returning to optimal evening sleep schedules until their next week. For those who work 90 hours a week, their high rate of productivity only is possible if they begin their next work cycle immediately after finishing the 34 hours required in the reset provision of the multi-day rules. These drivers working about 90 hours a week, while more productive, also are expected to have higher crash risk increments. We call work weeks in which the work cycles do not allow driver schedules to reset their sleep time "hard" rolling schedules, while those that do we call "soft" rolls.

8.6.4 Spreadsheet LH Crash Increment Calculations

After generating each rolling and non-rolling schedule modeled for each driver proportion cell, we calculate the crash risk increments by feeding the schedules into the Sleep/Performance spreadsheet. Results for driver schedules with stable working and sleeping patterns are displayed in Exhibit 8-7. Other results are found in Appendix F, section 4.

Exhibit 8-7
Modeled LH Crash Increment Results, Stable Work/Sleep Pattern

Hours Work / Day	Days Work / Week				
	3	5	6	7	8
9	10%	14%	16%	18%	20%
11	13%	18%	20%	23%	26%
13	14%	21%	24%	28%	32%
15	23%	34%	41%	48%	57%

Percentages rounded for presentational purposes.
Source: ICF Analysis, RoutePro Simulations

The interpretation of the crash increment in Exhibit 8-7 is that the Sleep/Performance spreadsheet indicates that drivers with stable work schedules who work nine hours a day three days a week under the ATA option have a 10 percent higher crash increment than in the baseline in which drivers receive 8.25 hours of sleep nightly. In contrast, the spreadsheet indicates that those with stable work schedules who are on-duty 15 hours a day eight days per work week have a 57 percent higher crash increment than the baseline.

8.6.5 Weighting Crash Increments, Productivity and Proportion Fatigue-Related

The crash risk increments calculated in section 8.6.4 are multiplied by the percentage of drivers found in each cell in the driver schedule proportion matrices. This calculation is made for each proposal option for rolling and non-rolling schedules. The resulting value is subtracted from the baseline crash increment under schedules with eight hours of regular sleep for an interim crash increment score for each scenario – current compliance status quo, current rule with full compliance, PATT, ATA, and FMCSA.

We adjust these interim crash increments for the differences in productivity found through these calculations from the productivity found in generating the cost estimates. We scale crash risk estimates up or down using the ratio of productivity found in the cost analysis to that found in the crash risk analysis.

We then multiply the results by the proportion of truck crashes in which fatigue may have played a role. Only truck crashes in which truck driver fatigue is considered to have potentially played a role are included in this proportion. The productivity adjustments and the raw fatigue-related crash increments calculated across all cells in a driver proportion matrix are shown in Exhibit 8-8.

Exhibit 8-8
Raw LH Crash Increment and Productivity Adjustment

Scenario	Raw Crash Increment vs Baseline	Productivity Adjustment Factor
Status Quo	11.5%	0.0%
Current, Fully Enforced	8.4%	5.7%
PATT	6.0%	0.0%
FMCSA	7.0%	0.0%
ATA	10.3%	0.0%

Source: ICF analysis

The final step discussed in this section is to convert the raw crash increment into the percentage of crashes that are related to fatigue. We start with the incremental crashes for each option that occur due to fatigue (raw fatigue increment). This number does not represent fatigue-related crashes as a proportion of all crashes, which ultimately is the proportion of interest. To calculate this proportion, which we call the fatigue-related percentage, we divide the raw fatigue increment by total crashes. That is, we divide the raw fatigue increment (from the first column of Exhibit 8-8) by the sum of the fatigue increment and the baseline of crashes before the fatigue increment. The baseline percentage of crashes before adding the fatigue increment is simply 100 percent. The sum of the raw fatigue increment plus the baseline percentage of total crashes is the raw fatigue increment plus 100 percent. The percentage of fatigue-related crashes, therefore, is the raw crash increments divided by 100 percent plus the raw crash increment or (raw increment)/(100 percent + raw increment).[145]

[145] As an example for clarification, suppose for the status quo that the fatigue increment were 100 percent. That is, in this hypothetical example, fatigue causes as many crashes in the status quo as would occur without driving under fatigued conditions. Fatigue, however, would not cause 100 percent of all crashes – only half. This percentage is calculated by dividing 100 percent by 100 percent + 100 percent, or 100 percent/200 percent = 50 percent.

In terms of our actual calculations for the status quo scenario, we divide the raw crash increment of 11.5 percent by 100 percent plus 11.5 percent or 11.5 percent /(100 percent +11.5 percent) = 10.3 percent. The result of these calculations are shown in Exhibit 8-9.

Exhibit 8-9 also presents the equivalent fatigue-related crash results from the analysis of SH operations described in Section 8.5.

Exhibit 8-9
Crash Increment and Fatigue-Related Crashes

	Scenario	Current/ 100%	PATT	ATA	FMCSA	Status Quo
LH	Raw Crash Increment vs. Non-Fatigued Baseline	8.4%	6.0%	10.3%	7.0%	11.5%
	Fatigue-Related Crashes	7.8%	5.7%	9.4%	6.5%	10.3%
SH	Raw Crash Increment vs. Non-Fatigued Baseline	3.6%	3.3%	3.6%	3.5%	3.7%
	Fatigue-Related Crashes	3.4%	3.2%	3.5%	3.4%	3.6%

Source: ICF analysis

8.6.6 Calibration of Sleep Performance (SP) Spreadsheet Results to Empirical Fatigue Crash Estimates

Because the SP spreadsheet is based on predictions of changes in simulated crashes rather than real-world experience, it cannot be used directly to estimate the percentage of crashes attributable to fatigue. Instead, that percentage was estimated independently (as presented in Section 8.3, on the basis of crash data. To ensure that they map well to the real world, the spreadsheet results need to be adjusted so that the scenario representing the status quo corresponds to this independent estimate of fatigue-related crashes. This section presents the method used to make that adjustment.

As presented in Section 8.6.5 above, the SP spreadsheet projected the fatigue-related crash percentage (relative to what would be expected for non-fatigued drivers) of 10.3 percent for LH operations and 3.6 percent for SH operations. Thus, the percentage of fatigue-related crashes is projected to be just under three times as great for LH as for SH operations. This difference is not surprising, given that SH drivers are much more likely than LH drivers to work during the day, sleep at home at night, and are less likely to be pushed to work extremely long hours. Previous research supports this general conclusion; the preliminary RIA reported on the basis of analysis of the TIFA database that for trips with an intended distance of over 200 miles, "the relative risk of fatigue-related crash – that is, the probability of fatigue given that a truck is involved in a fatal crash – is twice that of all vehicles. For trucks on trips of 500 miles or more, the relative risk is even higher, at 2.35."[146] The same document concluded that "Clearly, the data indicate that

[146] *Preliminary Regulatory Evaluation and Regulatory Flexibility Act Analysis, Hours of Service NPRM,* Federal Motor Carrier Safety Administration, April 2000, p. 28.

whatever definition is used, local drivers are significantly less likely than others to be involved in a fatigue related crash."[147]

Section 8.2 indicated that LH operations, as defined for this analysis, account for 61.8 percent of fatal truck crashes, 55 percent of injury-only truck crashes, and 59 percent of property-damage only crashes. Weighting by the number of crashes in each category, we find that LH operations accounted for 58.2 percent of all crashes, with SH operations accounting for the remaining 41.8 percent. Section 8.2 also indicated that fatigue accounted for 8.15 percent of all fatal truck crashes. Combining these percentages with the SP spreadsheet results showing fatigue-related increments of 3.6 percent and 10.3 percent for SH and LH operations respectively, we find that all of the estimates can be reconciled if the SP spreadsheet estimates are multiplied by an appropriate factor. This factor was found by setting up the following equation for X, the factor by which the SP spreadsheet estimates are to be multiplied:

$$41.8\% * 3.6\% * X + 58.2\% * 10.3\% * X = 8.15\%$$

Rearranging terms and solving, we find that $X = 8.15\%/(41.8\%*3.6\%+58.2\%*10.3\%) = 8.15\%/7.45\% = 1.0917$.

Thus, the SP spreadsheet can be calibrated to yield the 8.15% overall fatigue-related crash risk if the SP spreadsheet estimates of the crash increments are multiplied by 1.0917, producing fatigue-related increments of 3.9 and 11.2 percent for SH and LH respectively.

Calibrating the estimates of the percentage of fatigue-related crashes for all of the options by multiplying by 1.0917, we obtain the estimates presented in Exhibit 8-10.

Exhibit 8-10
Percentage of Crashes Attributable to Fatigue, as Modeled and After Calibration

		Current/ 100%	PATT	ATA	FMCSA	Status Quo
LH	**Uncalibrated**	7.8	5.7	9.4	6.5	10.3
	Calibrated	8.5	6.2	10.2	7.1	11.2
SH	**Uncalibrated**	3.4	3.2	3.5	3.4	3.6
	Calibrated	3.8	3.5	3.8	3.7	3.9

Source: Exhibits 8-9 and ICF calculations.

8.7 Risks Associated with New Drivers

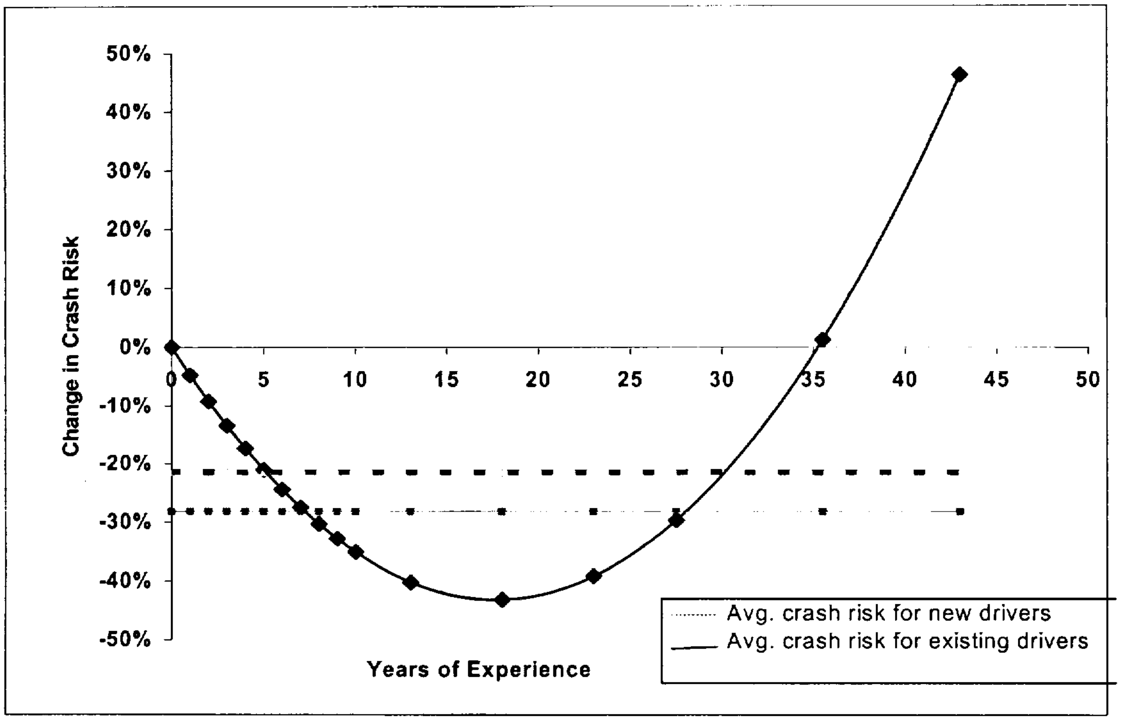
A secondary impact of the proposed HOS options would be to change the number of relatively inexperienced drivers that operate in the trucking industry. Since there is evidence in the literature linking experience with accident rates, any changes in the number of inexperienced drivers would correspondingly change the overall accident rates for all drivers under the HOS options considered.

Calculations for the changes in accident rates for new drivers were performed using data from the UMTIP driver survey and the discrete time proportional crash hazards model estimated for

[147] *Ibid.*, p. 30.

drivers based on that data.[148] Using the regression coefficients for experience and its squared term from that model, and data on driving experience from Abrams, *et al.* (1997),[149] we estimated a functional relationship between changes in crash risk difference and driving experience for truck drivers. Exhibit 8-11 shows that relationship.

Exhibit 8-11
Effect of Experience on Crash Risk



Source: ICF analysis of UMTIP and DFACS data.

Based on the functional relationship shown above, we estimated a 28 percent average reduction in crash risk for existing drivers over their lifetime of driving. Given the coefficients on years of experience and its squared term, we also estimated a 10-year weighted average change in accident rates for new drivers. The 10-year time horizon was chosen to be consistent with the time period used in this analysis for the costs and benefits calculations.

The weights used for this calculation are based on the distribution of experience levels for new drivers. According to conversations with industry analysts, approximately 85 percent of new drivers come in without any driving experience outside of their training and the remaining 15 percent is estimated to have an average 4 years of driving experience. Since these numbers are arbitrarily based on the current industry conditions, we conduct a sensitivity analyses around

[148] See Michael Belzer, *et al.* "Pay for Safety: An Economic Alternative for Truck Driver Safety", FMCSA, January 2002.

[149] See C. Abrams, T. Schultz, C.D. Wylie. "Commercial Motor Vehicle Driver Fatigue, Alertness, and Countermeasures Survey." Sponsored by U.S. Department of Transportation, Federal Highway Administration. August 1997.

them to see the changes it would bring about in the accident rates. Using these numbers, we calculate the changes in crash risk resulting from the changes in labor demand under the different HOS options.

There is evidence that suggests that the high turnover rates, especially in the TL segment, have been driven by the nature of the hours of service,[150] among other factors. Based on our conversations with industry experts on driver retention, the proposed new rules could have a positive impact on turnover to the extent that they make the work schedules in this profession similar to some of the other blue-collar occupations. They also feel that the industry does not have adequate human resource programs to retain drivers, leading to the highest turnover rates within the first 12 months of tenure. If the HOS options could bring about any reductions in people leaving trucking because their expectations are not met, we believe that it could reduce the need for hiring new inexperienced drivers[151] and change the composition of the new driver pool.

Moreover, according to some industry experts, there is a growing tendency among trucking companies to only hire new drivers with some experience, e.g., at least one year. This trend can also increase the average level of experience for the new drivers, as well as change the composition of drivers with/without experience in our analysis.

Since we do not have data on reduction in turnover because of the proposed new rules and/or fraction of the companies that only hire new drivers with some experience, we look at a case where only 50 percent of the new drivers come in with no experience and the rest with 4 years of experience. We also look at an extreme case where 99 percent of the new drivers have no experience. The results of this analysis are presented in Exhibit 8-12.

Exhibit 8-12
Estimated Crash Risk Changes for the Different HOS Options

Percentage share of new drivers with		Total change in crash risk under							
		PATT		ATA		FMCSA		Status Quo	
No Experience	4-year Experience	LH	SH	LH	SH	LH	SH	LH	SH
50%	50%	0.11%	0.20%	-0.14%	-0.01%	-0.10%	0.06%	-0.21%	-0.02%
85%	15%	0.27%	0.52%	-0.36%	-0.03%	-0.26%	0.14%	-0.55%	-0.05%
99%	1%	0.34%	0.65%	-0.45%	-0.03%	-0.33%	0.18%	-0.68%	-0.06%

Source: ICF analysis of UMTIP and Abrams, *et al*, data.

Note that negative crash risk percentages imply that under that particular HOS option in that market segment, there is actually a reduction in overall crash risk from implementing the HOS option because of a decrease in labor demand (or increase in labor productivity) from the proposed new rule. Also, the crash risk percentages are calculated from a baseline assuming 100-percent compliance with the current rules.

[150] See Gallup Organization study: "Empty Seats and Musical Chairs: Critical Success Factors in Truck Driver Retention", 1997, and discussion of these issues in detail in Chapter 6.

[151] What is also worth mentioning is that tenure seems to be a bigger problem for TL companies, more than inexperience. Driver retention rates are very low and improving HOS can have a positive impact on that.

The largest increase in overall accident rates due to hiring new, inexperienced drivers occurs under the PATT option, with the short haul outweighing the long haul accident rates differences. This is directly proportional to the large changes in labor demand predicted for the short haul for the PATT option. However, the magnitudes of the rate increases are generally less than or close to half a percent, with the highest being 0.65 percent if almost all of the new drivers come in with no experience. The only other column in the table that gives increases in accident rates is for the short haul under the FMCSA option.

The main conclusion from the table given above is that although we do expect an increase in accident rates if there is a need to hire new drivers from any of the proposed options, the relative increases in their crash risk probabilities are not that alarming. The implication of hiring new drivers would indeed be a reduction in benefits, the details of the calculations are provided in Chapter 9.[152] The table also suggests that the increase in accident rates for new drivers is not very sensitive to the composition of experience levels for new drivers, in that the changes in crash risks from the top row of the table to the bottom is generally much smaller than one percent whereas the risk reductions provided by the options are on the order of several percent (as shown in Section 8-8, below). Thus for the purpose of this study, we use the 85 percent – 15 percent division to calculate the changes in dollar benefits.

8.8 VALUE OF CRASH REDUCTIONS

The total damages from all large truck crashes can be found by multiplying the total number of crashes by the average damage imposed per large truck crash. Numbers of crashes by severity were presented in Exhibit 8-1, and are reproduced in Exhibit 8-13 in summary form. The average value of damages per crash shown in the exhibit, $75,637, is based on research for the Department of Transportation.[153] Multiplied together, the total number of crashes and the value of damages per crash yield total annual damages of over $32 billion.

[152] We also analyzed the comment provided by Distribution and LTL Carriers Association on this issue (FMCSA Docket No. 1997-2350-20928). The analysis presented in it is based on data from Florida's accident rates in 1989 which showed that new drivers are 1.27 times more likely to have an accident than older drivers. Using the 48,849 new drivers needed due to HOS changes, estimated by FMCSA in its preliminary RIA as the sample, the authors calculate these new drivers could have "as many as 13,000 (more) crashes" (27% of 48,849=13,189). However, the analysis is flawed because it assumes that older drivers in the control group have an accident rate of 1accident per driver per year (or 100% accident rate) and therefore a 27% increase for new drivers converts to a 27% increase in the number of accidents per year. According to survey data collected by UMTIP in 1997, accident rates for drivers is about 15% per year (See Kristen Monaco and Emily Williams: "Assessing the Determinants of Safety in the Trucking Industry" Journal of Transportation and Statistics, April 2000, page 4). Using that, one would get 4% increase in accident risk for new drivers or probability of 1,978 accidents (27%*15%*48,849). Also, data used for the analysis comes from Florida's accident rates in 1989. We analyzed more recent data which indicated that accident rates for large trucks have decreased significantly (from 3.3/100million VMT in 1989 to 2.2/100 million VMT in 2000. See "Large Truck Crash Facts 2000" FMCSA Analysis Division). Moreover, data from 1990 to 2000 also indicate that Florida has consistently had about 3 times the crash rates as the national average, which makes it problematic to use Florida as a representative sample.

[153] Zaloshnja E., Miller T., Spicer R., "Costs of Large Truck-and-Bus Involved Crashes", p. 22, Table 11, October 2000.

Exhibit 8-13
Calculation of Total Value of Large Truck Crashes by Year

	Average per Year
Fatal Crashes	4,568
Injury Crashes	92,000
Property Damage Only Crashes	329,250
Total Large Truck Crashes	425,818
Average Damages per Large Truck Crash	$75,637
Total Damages from Large Truck Crashes (millions)	$32,208

Source: Exhibit 8-1, "Costs of Large Truck- and Bus-Involved Crashes," Zaloshnja *et al.*, Table 10.

This total value of damages can be divided between LH and SH operations using the breakdowns of crashes by length-of-haul and severity presented in Section 8.2. Dividing the total number of crashes of each severity level into LH and SH using the percentages shown in the second and third columns of the exhibit below, and summing for all three crash severities, yields the total number of crashes for each length of haul. Multiplying these totals by the average value per crash yields an approximate value of damages from all LH and SH crashes. These estimates are only approximate because the damages per crash differ by crash severity, and the breakdown of crashes by length of haul differs according to the severity of the crash.

The last line of Exhibit 8-14 shows the effect of excluding two groups of LH drivers from the calculation of benefits. We do not expect that drivers in these two relatively small groups – team drivers (for both private fleets and for-hire carriers) and the LH drivers in LTL carriers – to have their work schedules significantly affected by changes in the HOS rules. The changes in fatigue-related crashes estimated to result from the options would not apply to these drivers or to the crashes that involve them. We therefore reduced the damage estimate for LH crashes by 14.6 percent, which is our estimate of the percentage of LH VMT accounted for by these drivers (see Exhibits 3-1 and A-1, which shows a total of about 24 billion VMT for team drivers plus LH LTL drivers, out of a total LH VMT of about 165).

Exhibit 8-14
Division of Crashes and Crash Damages by Length of Haul

	LH %	SH %	LH Crashes	SH Crashes	Total
Fatal Crashes	61.8	38.2	2,823	1,745	4,568
Injury Crashes	55.0	45.0	50,600	41,400	92,000
Property Damage Only Crashes	59.0	41.0	194,258	134,993	329,250
Total Large Truck Crashes	58.2	41.8	247,681	178,137	425,818
Average Damages per Large Truck Crash			$75,637	$75,637	$75,637
Total Damages (millions)			$18,734	$13,474	$32,208
Total Damages, Excluding Largely Unaffected LH Drivers (Team and LTL LH)			$15,999	$13,474	$29,472

Source: Exhibits 8-3 and 8-13, ICF calculations. Totals may not add due to rounding.

Exhibit 8-15
Damages Attributable to Fatigue by Option

		Current/ 100%	PATT	ATA	FMCSA	Status Quo
LH	Percentage of Crashes Attributable to Fatigue	8.5%	6.2%	10.2%	7.1%	11.2%
	Total Damages of Fatigue-related Crashes (millions)	$1,361	$997	$1,628	$1,138	$1,791
SH	Percentage of Crashes Attributable to Fatigue	3.8%	3.5%	3.8%	3.7%	3.9%
	Total Damages of Fatigue-related Crashes (millions)	$506	$470	$514	$492	$528

Source: Exhibit 8-1, Exhibit 8-10, ICF calculations.

9. COST AND BENEFIT RESULTS

This chapter presents the results of the analysis in terms of social costs, benefits, and net benefits. Cost-related results are summarized first, followed by changes in crashes and resulting benefits. In general, the costs and benefits of the options are presented relative to a baseline that assumes 100 percent compliance with the current rules ("Current/100%"). The costs and benefits of the options relative to a "status quo" baseline, with current compliance levels, are presented in abbreviated form at the conclusion of the chapter. In addition, this chapter shows the effect on costs, benefits, and net benefits of a variant of the FMCSA option, which allows less flexibility in SH operations.

9.1 COSTS OF THE OPTIONS

This section presents the results of the cost analysis. We first summarize the required changes in drivers for LH and SH operations. Initially, the changes are shown under assumptions of constant demand for trucking services; the adjustment for mode shifts is presented later. We then present the implications of these changes in drivers for costs.

Given the primary changes in drivers and costs, we consider two secondary effects: changes in drivers' wages, and mode shifts between LH truck and rail. Feedback from these secondary changes would, in theory, cause further ramifications, but these are not analyzed because we found that they would be very small. For example, the effect of the mode shift on the number of drivers would be about an order of magnitude smaller than the direct effects of the options. The effects of these additional drivers on wages and carrier operating costs would be within the rounding error of the analysis of the mode shifts, so there was no need to take them into account.

Exhibit 9-1 presents the percentage changes in drivers required that were calculated in the analysis of changes in operations, and then shows their implications for total numbers of drivers on the basis of our estimates of total LH and SH drivers.

Exhibit 9-1
Changes in Drivers Needed in Response to HOS Limits
Relative to Current Rules with Full Compliance

		PATT	ATA	FMCSA
Percentage Change	LH	4.0%	-5.3%	-3.9%
	SH	7.7%	-0.4%	0.7%
Numbers	LH	60,000	-79,500	-58,500
	SH	115,500	-6,000	10,500
	Total	175,500	-85,500	-48,000

Source: ICF Analysis

Exhibit 9-2 shows, for the LH sector, the cost implications of the changes in drivers shown in Exhibit 9-1. The cost changes are divided into directly driver-related cost changes, and the costs of non-driver related changes that are necessary as a result of the changes in numbers of drivers. For each option, there are costs related to new driver wages and benefits, which counteract the changes in wages and benefits for current drivers whose hours of work have changed. The net cost (or cost savings) for the drivers comes about because the per-hour cost of work that has been shifted between existing drivers and newly hired drivers is not the same for the two groups: average employment costs for newly hired drivers tend to be higher than the per-hour cost of extra hours for existing drivers, in part because of fixed payroll costs (e.g., benefits) per driver. Other costs include costs for purchasing, maintaining, insuring, and parking additional tractors and trailers for the new drivers, and hiring a larger staff of non-driving personnel to handle larger numbers of drivers.

Exhibit 9-2
Direct Cost Changes – LH
(millions of dollars per year)

Cost Category	PATT	ATA	FMCSA
Driver Labor Cost	287	-792	-636
Avoided Labor Wages	-1,953	2,258	1,546
Avoided Labor Benefits	-117	136	92
New Labor Wages	1,799	-2,433	-1,736
New Labor Benefits	558	-754	-538
Other Costs	478	-563	-437
Nondriver Labor	11	-32	-25
Trucks	228	-216	-179
Parking	54	-72	-53
Insurance	40	-52	-39
Maintenance	70	-93	-68
Recruitment	75	-99	-73
Total Costs	764	-1,356	-1,073

Source: ICF analysis. Totals may not add due to rounding.

Exhibit 9-3 shows similar calculations for SH operations, and Exhibit 9-4 reports total direct cost changes.

Exhibit 9-3
Direct Cost Changes – SH
(millions of dollars per year)

Cost Category	PATT	ATA	FMCSA
Driver Labor Cost	1,557	-38	90
Avoided Labor Wages	-3655	165	-298
Avoided Labor Benefits	-219	10	-17
New Labor Wages	3798	-150	309
New Labor Benefits	1633	-64	96
Other Costs	1038	-49	78
Nondriver Labor	62	-2	4
Trucks	517	-23	33
Parking	105	-5	10
Insurance	76	-4	7
Maintenance	134	-7	12
Recruitment	144	-7	13
Total Costs	2595	-87	168

Source: ICF Analysis. Totals do not add due to rounding.

Exhibit 9-4
Total Direct Cost Changes
(millions of dollars per year)

	PATT	ATA	FMCSA
LH	764	-1,356	-1,073
SH	2,595	-87	168
Total	**3,360**	**-1,442**	**-905**

Source: ICF analysis. Total do not add due to rounding.

We analyzed two secondary effects of the need to change the number of drivers in response to the HOS rule options: wage rate changes due to the need to draw new drivers into the industry, and mode shifts in response to changes in the costs of LH operations. The changes in drivers shown in Exhibit 9-1 were first translated into changes in market wage rates for drivers using a driver supply elasticity of 5.0. The resulting percentage changes in wages are shown in the second line of Exhibit 9-5. The effects of that increase on the total costs of the long-haul sector are presented in the next line, followed by the total increase in LH costs including both the costs for changes in labor and capital, and the costs due to the wage increases. This total cost increase is then compared to the total costs for all LH operations to yield a percentage increase in LH costs.

Exhibit 9-5
LH Cost Changes Including Wage Increases and Resulting Mode Shifts
(Costs in millions of dollars per year)

	PATT	ATA	FMCSA
Direct HOS-Induced Costs, LH Only	764	-1,356	-1,073
Percentage Change in Wages due to Driver Supply Elasticity	1.2%	-0.6%	-0.3%
Change in LH Wage Bill due to Wage Increases	752	-366	-206
Total Change in LH Costs	1,517	-1,722	-1,279
Percentage Increase in LH Costs	0.4%	-0.4%	-0.3%
Percentage Change in LH VMT due to Mode Shift	-0.32%	0.37%	0.25%
Change in LH Drivers due to Mode Shift	(-4,875)	5,535	3,820

Source: ICF analysis.

Given this percentage increase in LH costs, the assumption that this cost increase is passed on to shippers, a measure of the sensitivity of mode choice to prices, and an estimate of the portion of the LH sector that is sensitive to competition from rail, we estimated the percentage change in LH VMT that would result from changes in the mode split. Assuming a constant relationship between drivers and VMT allowed us to estimate the change in LH drivers resulting from the projected mode shift. The LH wage increases and changes in mode shifts are not included elsewhere in the report because these represent transfers in welfare among groups and not net social costs to society. Only the direct costs are reported in the remainder of the report.

9.2 BENEFITS

The quantified and monetized benefits of the options derive from their effects on truck crashes. The safety analysis presented in Chapter 8 and in Appendix A showed how the changes in work and sleep schedules induced by the HOS options could be translated in relative changes in modeled fatigue-related crashes, how these changes could be calibrated to correspond to independent estimates of numbers of fatigue-related crashes, and (in Section 8) what the damages from fatigue-related crashes are projected to be under each of the options. This section first presents, as benefits, these changes in damages for LH and SH operations. Two other sources of benefits (or reductions in benefits) are then described: changes in damages resulting from the employment of different numbers of new drivers, and changes in damages in LH operations resulting from shifts between truck and rail.

9.2.1 Changes in Crash Damages due to Schedule Changes

The benefits of the options in terms of the annual values of the crash reductions shown in Exhibit 9-6 were found by subtracting the damages under each option from the damages for the current rules with 100 percent compliance.

Exhibit 9-6
Value of Crashes Avoided Due to Operational Changes
Relative to Current Rules with Full Compliance
(Millions of dollars per year)

	PATT	ATA	FMCSA
Benefits of Avoided LH Crashes	364	-267	224
Benefits of Avoided SH Crashes	36	-8	10
Total Benefits	400	-275	234

Source: ICF Analysis

Overall, fatigue-related crashes were predicted to be significantly more of a problem in LH than SH operations. This fact can be attributed in part to the somewhat heavier work schedules of long-haul drivers, but also to the fact that LH operations appear more likely to subject drivers to irregular and rotating schedules. Two of the options, PATT and FMCSA, are projected to reduce accidents substantially relative to the current rules with full compliance. Much of their effectiveness stems from the greater likelihood of moving towards a 24-hour work-rest cycle with decreased schedule rotation; they also allowed for increased sleep during the work week. Reductions in SH crashes were much smaller than the reductions in LH crashes, both in relative and absolute terms.

9.2.2 Changes in Fatigue-related Fatalities due to Schedule Changes

Beyond valuing the benefits of the options, it is useful to present the changes in fatalities that they cause. Estimating fatigue-related fatalities and changes in them can be done most easily by referring to the total annual number of fatalities in truck crashes, presented in Exhibit 8-1, splitting that number between LH and SH operations using the data presented in Exhibit 8-3, and then multiplying by the fatigue-related percentages by option shown in Exhibit 8-14. Changes in fatalities can then be calculated by comparing the fatigue-related fatalities for the different options.

Exhibit 8-1 gives the total annual fatalities in truck crashes as 5,346; this is slightly larger than the number of fatal crashes because some crashes cause multiple fatalities. Of these, 61.8 percent or 3,304 are estimated to occur in LH operations, with the other 2,042 in SH operations.

Among the LH fatalities, we concentrate on the 85.4 percent or 2,821 that we estimate to occur in those portions of the LH sector that would be most affected by the rules (i.e., excluding team-driver and LTL operations).

Multiplying the 2,821 LH fatalities and 2,042 SH fatalities by the fatigue-related percentages shown in Exhibit 8-14 yields fatigue-related fatalities. For the Status Quo, these calculations yielded estimates of 316 for LH and 80 for SH, for a total of 396. For the options, the estimates are shown below in Exhibit 9-7. The exhibit also shows the changes in fatalities relative to the current rules with full compliance.

Exhibit 9-7
Annual Fatigue-related Fatalities by Option

		Current/ 100%	PATT	ATA	FMCSA	STATUS QUO
LH	Fatalities in Crashes Attributable to Fatigue	240	176	287	201	316
	Differences by Option Relative to Current/100%	NA	- 64	47	- 39	76
SH	Fatalities in Crashes Attributable to Fatigue	77	71	78	75	80
	Differences Relative to Current/100%	NA	- 5	1	- 2	3
Total	Fatalities in Crashes Attributable to Fatigue	317	247	365	276	396
	Differences by Option Relative to Current/100%	NA	- 70	48	- 41	79

Source: Exhibit 8-1, Exhibit 9-6, ICF calculations. Totals do not add due to rounding.

9.2.3 Adjustments to Benefits due to Secondary Effects

The crash reductions benefits shown in Exhibit 9-6 include only effects of schedule changes on driver fatigue. While these are the primary effects of HOS rules, two secondary effects need to be considered. First, the changes in drivers resulting from the schedule changes and mode shifts, presented in Exhibits 9-1 and 9-5, will result in changes in the number of relatively inexperienced drivers in the industry. As described in Section 8.7, these drivers tend to have somewhat higher accident rates than the average driver, even over the fairly long time horizon considered in this analysis. Second, the changes in LH VMT resulting from the mode shift (discussed above) can be expected to result in proportionate changes in LH accidents. Both of these secondary effects are presented in Exhibit 9-8, which shows the effects in terms of their effects on benefits: increased crashes are shown as negative impacts on benefits in the exhibit, while reduced crashes are shown as positive values. The exhibit also shows the total benefits of each option after the adjustments for these secondary effects.

Exhibit 9-8
Adjustments to Benefits Due to Secondary Effects of Options: New Drivers and Mode Shift (Millions of dollars per year)

	PATT	ATA	FMCSA
Change in Benefits due to New LH Drivers	- 51	67	49
Change in Benefits due to New SH Drivers	- 70	4	- 6
Change in Benefits due to New LH and SH Drivers	**- 121**	**71**	**42**
Changes in Benefits due to Increases in LH VMT	61	- 69	- 48
Change in Benefits due to Both Secondary Effects	**- 60**	**2**	**- 5**
Total Unadjusted Benefits (from Exhibit 9-6)	**400**	**-275**	**234**
Total Adjusted Benefits	**341**	**-272**	**228**

Source: ICF analysis and Exhibit 9-6. Totals may not add due to rounding.

Along with these adjustments to benefits, there would be small adjustments to the changes in fatalities. These adjustments are shown in Exhibit 9-9 below.

Exhibit 9-9
Adjustments to Changes in Fatalities Due to Secondary Effects of Options, Relative to the Current Rules with Full Compliance

	PATT	ATA	FMCSA
Increase in LH Fatalities due to New Drivers	9	- 12	- 9
Increase in SH Fatalities due to New Drivers	11	- 1	1
Increase in Total Fatalities due to New Drivers	20	- 13	- 8
Increase in LH Fatalities due to Changes in LH VMT	- 11	12	8
Net Increase in Fatalities due to Secondary Effects	9	0	1
Total Unadjusted Change in Fatalities	-70	48	-41
Total Adjusted Change in Fatalities	- 61	48	- 40

Source: Exhibit 9-7, ICF calculations. Totals may not add due to rounding.

9.3 Net Benefits

The net social benefits of the options, relative to the current rules with full compliance, are found by subtracting the social costs from the benefits. The results are shown in Exhibit 9-10, below.

Exhibit 9-10
Net Benefits Relative to Current Rules with Full Compliance (Millions of dollars per year)

	PATT	ATA	FMCSA
Total Benefits	341	-272	228
Total Cost	3,360	-1,442	-905
Net Benefits	**- 3,019**	**1,170**	**1,133**

Source: Exhibits 9-4, 9-8, and ICF calculations.

9.3.1 Discussion of Net Benefit Results

The analyses presented above (summarized in Exhibit 9-11, below) show that both the ATA and FMCSA options have net benefits compared to the current rules with full compliance (as exhibited by the positive benefits calculated). Of these two options, only the FMCSA option provides positive benefits compared to the current rules with full compliance; the ATA option has negative benefits that are outweighed by larger cost savings. The PATT option has somewhat higher benefits than the FMCSA option, but imposes costs that outweigh the additional benefits.

The relative costs and benefits of the options differ considerably between the LH and SH segments. Most of the costs of the more protective options, PATT and FMCSA, arise in the SH segment, but all of their benefits come from reducing LH crashes. Fatigue and fatigue-related crashes are considerably less common in SH operations, and the options that limit hours of work appear to be unlikely to make substantial reductions in those crashes. On the other hand, the need to hire many more drivers in response to the restrictions would cause increases in crashes over the ten-year time horizon of this study, and those additional crashes would counterbalance the small predicted reductions in fatigue-related crashes.

In LH options, though, the fraction of crashes attributable to fatigue is considerably larger, and the two protective options are predicted to reduce those crashes considerably. Considering the LH segment only, the FMCSA option is superior on net benefit grounds to the ATA and PATT options. Because the net benefits are positive relative to the current rules with full compliance, it is superior to this scenario as well.

Exhibit 9-11
Net Benefits by Length of Haul Relative to Current Rules with Full Compliance
(Millions of dollars per year)

		PATT	ATA	FMCSA
LH	Total Benefits	374	-269	225
	Total Cost	764	-1,356	-1,073
	Total Net Benefits	**- 390**	**1,087**	**1,298**
SH	Total Benefits	-34	-4	4
	Total Cost	2,595	-87	168
	Total Net Benefits	**-2,629**	**83**	**-164**
All	**Total Net Benefits**	**-3,019**	**1,170**	**1,133**

Source: Exhibits 9-4, 9-6, and 9-8, and ICF calculations. Totals may not add due to rounding.

9.3.2 Limitations and Sensitivities

In general, it should be kept in mind that many aspects of this analysis are highly uncertain, so the cost and (especially) the benefit estimates must be viewed with caution. One important source of uncertainty is the magnitude of the effects of "time on task" on crash risks. As discussed in Chapter 8.1.5, there is likely to be an increase in risk as continuous hours of driving increase that is independent of the effects of circadian rhythms and sleep deficits. We were not able to model this independent effect, however, due to uncertainty about its magnitude for very long hours of driving. If that effect were actually large, the more protective options would show relatively higher benefits. Uncertainty about the time-on-task effect is particularly great for very long hours of driving, in part because very long driving shifts are not permitted. They are therefore both rare and difficult to study. In particular, the 16-hour driving shifts that would be allowed at times under one of the options (a provision that was not modeled for the LH analysis) would be very rare and hard to study under real world conditions.

Another important source of uncertainty lies in the independent estimate of the percentage of crashes in the status quo that can be attributed to fatigue. Though we believe our estimates to be as realistic as possible, both much lower and much higher values have been put forth, and the benefit estimates in this analysis are largely proportional to the fatigue percentage.

In Chapter 8, we estimated that 8.15 percent of crashes are fatigue-related. Exhibit 9-12 shows the effects of different assumptions about the percentage of fatigue-related crashes in the baseline. The exhibit shows net benefits for the three options relative to the current rules with full compliance under three assumptions about the baseline fatigue-related crash percentage: the 8.15 percent estimated in the course of this analysis, a lower rate of 5 percent, and a higher rate of 15 percent. Many individuals and organizations commented on the NPRM's estimate of the percentage of fatigue-related crashes. A large majority of commenters suggested that the correct figure fell within the 5 to 15 percent range.

The results presented in the exhibit show increasing net benefits for the PATT and FMCSA options as baseline fatigue crashes increase, and decreasing net benefits for the ATA option. These improvements in net benefits for the PATT and FMCSA options result from the combination of constant costs (i.e., the costs of the options are not affected by the fraction of crashes caused by fatigue) and the scaling-up of their fatigue-prevention effects. In other words, because these options both prevent a large share of the fatigue-related crashes, their benefits rise with the number of fatigue-related crashes. If costs do not change, the increase in benefits results in an increase in net benefits as well. The ATA option, by contrast, shows a reduction in benefits and net benefits as fatigue becomes a larger factor in crashes because it results in more fatigue-related crashes than the current rules. The ATA and FMCSA options are comparable in terms of net benefits if 8.15% of crashes result from fatigue, while the ATA option has higher net benefits for lower percentages and the FMCSA options has higher net benefits for higher percentages.

Exhibit 9-12
Sensitivity of Net Benefits to Baseline Fatigue-Related Crash Percentage
Relative to Current Rules with Full Compliance
(Millions of dollars per year)

	PATT	ATA	FMCSA
Net Benefits, 5% Fatigue Crashes	- 3,174	1,276	1,043
Net Benefits, 8.15% Fatigue Crashes	- 3,019	1,170	1,133
Net Benefits, 15% Fatigue Crashes	- 2,682	939	1,326

Source: Exhibit 9-11 and ICF calculations.

As noted in 9.3.1, reviewing the costs and benefits by length of haul reveals that the options have very different cost/benefit profiles for LH compared to SH operations. The FMCSA option, for example, provides net benefits in LH operations, but has net costs for SH.

The observation that the options are less cost-effective in SH operations was part of the motivation for providing more flexibility in the FMCSA option for SH drivers, allowing one 16-hour shift per week. We assessed the effects of this flexibility by examining the costs and benefits of the FMCSA option without allowing any 16-hour shifts.

Our analysis showed that, for SH operations, this change would more than triple the annual costs of the FMCSA option relative to the current rules with full compliance. Costs would increase from $164 million to $646 million, or by almost $500 million per year. The majority of these costs result from the short-haul segment of operations. These additional costs would translate almost directly into a reduction in net benefits, because the effects of the reduced flexibility on crashes would be very small. We estimate that, because the increase in the need for new SH drivers would more than offset the slight reduction in fatigue-related accidents, prohibiting 16-hour shifts would worsen the crash-reduction benefits slightly: total benefits would fall by about $10 million per year, and fatalities would rise by one or two per year.

With this change to the FMCSA option, its net benefits compared to current rules with full compliance would drop to about a half billion dollars per year. These results are shown in Exhibit 9-13.

Exhibit 9-13
Net Benefits by Length of Haul Relative to Current Rules with Full Compliance
(Millions of dollars per year)

		PATT	ATA	FMCSA	FMCSA, without SH Flexibility
LH	Total Benefits	374	-269	225	225
	Total Cost	764	-1356	-1073	-1073
	Total Net Benefits	**- 390**	**1,087**	**1,298**	**1,298**
SH	Total Benefits	-34	-4	4	-5
	Total Cost	2595	-87	168	641
	Total Net Benefits	**-2,629**	**83**	**-164**	**-646**
Total	**Total Net Benefits**	**- 3,019**	**1,170**	**1,133**	**652**

Source: Exhibit 9-11 and ICF calculations. Totals may not add due to rounding.

9.4 Costs and Benefits Relative to the Status Quo

This section recapitulates the costs and benefits presented in this chapter relative to a baseline representing the status quo. Exhibit 9-14 presents the changes in drivers needed relative to the Status Quo scenario; because the difference in drivers needed between the Status Quo and the Current Rules/100% is 8.1% for LH, that amount was added to the estimates that were presented in Exhibit 9-1 for each of the options. Similarly, the amount shown in the other rows of the "Current/100%" column in Exhibit 9-14 was added to the estimates presented in Exhibit 9-1 for each of the other options. Because achieving full compliance with the current rule would require more drivers, all of the values in 9-14 are higher than those in 9-1.

Exhibit 9-14
Changes in Drivers Needed in Response to HOS Limits, Relative to the Status Quo

		Current/ 100%	PATT	ATA	FMCSA
Percentage Change	**LH**	**8.1%**	**12.1%**	**2.8%**	**4.2%**
	SH	**0.7%**	**8.4%**	**0.3%**	**1.4%**
Numbers	LH	121,500	181,500	42,000	63,000
	SH	10,800	126,300	4,800	21,300
	Total	**132,300**	**307,800**	**46,800**	**84,300**

Source: Exhibit 9-1 and ICF Analysis.

The direct costs of the options relative to the Status Quo are shown in Exhibit 9-15. This exhibit shows the costs of the current rules with full compliance in the fourth column from the right. The other columns show selected cost data from Exhibits 9-2 and 9-3 with the cost of compliance with the current rules added. Because there would be costs for compliance with the current rules, the costs of each of the options are higher relative to the status quo than relative to the current rule with full compliance.

Exhibit 9-15
Direct Cost Changes Relative to Status Quo
(Millions of dollars per year)

Cost Category		Current/100%	PATT	ATA	FMCSA
LH	Driver Labor Cost	1,185	1,472	393	550
	Other Costs	769	1,247	206	332
	Total Costs	**1,954**	**2,719**	**599**	**882**
SH	Driver Labor Cost	143	1,700	105	233
	Other Costs	90	1,128	41	168
	Total Costs	**232**	**2,827**	**146**	**400**
Total Costs, LH and SH		**2,187**	**5,546**	**744**	**1,282**

Source: Exhibit 9-2 and 9-3 and ICF Analysis. Totals may not add due to rounding.

Exhibits 9-16 and 9-16 show the benefits and adjusted benefits of compliance with the current rule, as well as the options, relative to the status quo. They are based on Exhibits 9-6 and 9-8, with the benefits of compliance with the current rules added to the values in those exhibits. Because there would be substantial benefits to achieving full compliance with the current rule, the benefits shown in these tables are higher than those shown in Exhibits 9-6 and 9-8.

Finally, Exhibit 9-18 shows the net benefits of compliance with the current rule and of the options, relative to the Status Quo. This exhibit presents the total cost and total benefits lines from Exhibits 9-15 and 9-17, and subtracts costs from benefits to yield net benefits.

Exhibit 9-16
Value of Crashes Avoided Due to Operational Changes Relative to Status Quo
(Millions of dollars per year)

	Current/ 100%	PATT	ATA	FMCSA
Benefits of Avoided LH Crashes	429	794	162	653
Benefits of Avoided SH Crashes	22	58	14	32
Total Benefits of Operational Changes	451	852	176	685

Source: Exhibit 9-6 and ICF analysis.

Exhibit 9-17
Adjustments to Benefits Due to Secondary Effects of Options Relative to the Status Quo
(Millions of dollars per year)

	Current/ 100%	PATT	ATA	FMCSA
Change in Benefits due to New LH Drivers	- 103	- 154	- 36	- 54
Change in Benefits due to New SH Drivers	- 7	- 77	- 3	- 7
Change in Benefits due to New LH and SH Drivers	- 110	- 230	- 38	- 67
Change in Benefits due to Change in LH VMT	101	162	32	54
Net Damages (i.e., Reduction in Benefits due to Secondary Effects)	- 9	- 68	- 6	- 14
Total Unadjusted Benefits	452	851	176	685
Total Adjusted Benefits	443	783	170	671

Source: Exhibit 9-8 and ICF calculations. Totals may not sum due to rounding.

Exhibit 9-18
Net Benefits Relative to Status Quo
(Millions of dollars per year)

	Current/ 100%	PATT	ATA	FMCSA
Total Benefits	443	783	170	671
Total Costs	2,187	5,546	744	1,282
Net Benefits	-1,744	-4,763	- 574	-611

Source: Exhibits 9-13 and 9-15, and ICF calculations.

Exhibit 9-19 shows the effects of different fatigue-related crash percentage assumptions on net benefits relative to the status quo. Because all of the options, and the current rules under full compliance, are more protective than the status quo, all show improvements in benefits and net benefits as the fatigue-related percentage increases. The PATT option shows largest improvement in net benefits for higher fatigue percentages, but because of its high costs it still shows large negative net benefits for the highest fatigue percentage assumption. The FMCSA option's net benefits also improve considerably as the fatigue percentage increases; its costs are approximately equal to its benefits (that is, it is essentially comparable to the status quo) under the 15 percent assumption, and its negative net benefits are much larger under the 5 percent assumption.

Exhibit 9-19
Sensitivity of Net Benefits to Baseline Fatigue-Related Crash Percentage Relative to Status Quo
(Millions of dollars per year)

	Current/ 100%	PATT	ATA	FMCSA
Net Benefits, 5% Fatigue Crashes	-1,918	-5,092	- 642	-876
Net Benefits, 8.15% Fatigue Crashes	-1,744	-4,763	- 574	-611
Net Benefits, 15% Fatigue Crashes	-1,365	-4,047	- 426	-35

Source: Exhibit 9-12, and ICF calculations.

10. IMPACTS ON CARRIERS

The study considers firm impacts on long-haul truckload carriers in seven size categories, which are shown below with estimates (based on Chapter 3 and Appendix A) of the number of independent firms falling into each:[154]

- 1 tractor (32,800 firms)
- 2-9 tractors (9,800 firms)
- 10-19 tractors (3,500 firms)
- 20-50 tractors (3,500 firms)
- 51-145 tractors (1,800 firms)
- 146-550 tractors (600 firms)
- 550+ tractors (150 firms)

Carriers in the first five of these categories generally qualify as small entities under criteria established by the Small Business Administration (i.e., annual revenue of less than $21.5 million) for all North American Industrial Classification System (NAICS) codes falling under the truck transportation subsector (NAICS 484). Carriers typically exceed this threshold when they operate about 145 tractors or more.[155] The largest two categories encompass those long-haul carriers that do not qualify as small entities under the SBA criteria. The specific size categories enumerated above are intended to reflect natural groupings or breakpoints in terms of firm behaviors and economies of scale.

For representative carriers in each size category, the study estimated the financial impact of each regulatory option in terms of the change in net income to the carrier.[156] Chapter 3 summarizes the distribution of carriers by size category. Exhibit 10-1 summarizes the status quo baseline profitability of carriers in the various size categories. Note that Exhibit 10-1 (like many of the remaining exhibits in this chapter) does not address firms in the smallest size category (i.e., owner/operators with a single tractor) because the results for these entities require a slightly different interpretation than the results for other size categories. Owner/operators with one tractor are addressed in Section 10.3.

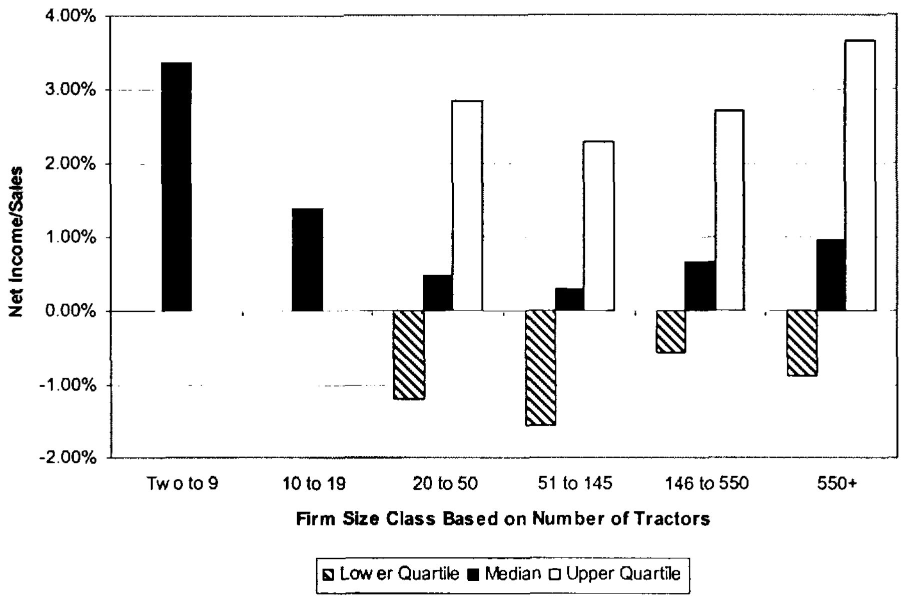
The remainder of this chapter is divided into three sections. Section 10.1 provides an overview of the results of the impact analysis. Section 10.2 organizes the results by regulatory option. Section 10.3 describes the results for the various carrier size categories.

[154] Impacts on the private fleet and LTL sectors are not expected to be significant. In the case of private fleets, firm impacts generally will be relatively small because trucking comprises only a small portion of firm activities. For reasons discussed in Chapter 5, section 5.1.2, the rule is expected to have minimal effects on the LH operations of LTL firms. The LH TL carriers examined in this chapter are those most affected by the rule and the options; most short-haul and local operations are conducted by private fleets and LTL firms, for which the SH operations are only a portion of their business. Furthermore, most of the options have only slight effects on SH costs.

[155] Based on analysis of data from the TTS Blue Book. This implies total revenue (i.e., from trucking plus other value-added services) averaging approximately $145,000 per tractor across all firm sizes.

[156] Representative carriers for the four largest size categories were selected on the basis of having the median value in the category for profitability (as measured by the ratio of net income to total revenue); for sensitivity analysis purposes, firms dividing the upper and lower quartiles also were selected. Due to data limitations, smaller size categories were evaluated based on model firms that are believed to be representative of the category as a whole. A more detailed discussion of the methodology used in this analysis is presented in Appendix H.

Exhibit 10-1
Baseline Profitability of Representative Carriers



10.1 Summary of Results

Of the three options evaluated in this study, only the PATT Option would result in significant, adverse financial impacts (reduced profits) on most carriers. Although both the ATA Option and the FMCSA Option would affect carrier finances, the resulting impacts generally would be favorable to carriers – that is, carriers in most size categories would become more profitable under either option than under the current rules with full compliance. Also, all carriers would be impacted more favorably under the ATA Option than under the FMCSA Option. These findings are consistent with the cost results presented in Section 9. (See Section 10.2 for further discussion of the results by option.)

In general, smaller firms are hurt more (under the PATT Option) or helped less (under either the ATA Option or the FMCSA Option) than are larger firms. Nevertheless, for either the ATA Option or the FMCSA Option, the rule generally will result in favorable impacts on all carriers (including owner/operators with one tractor) *except for* firms in the 2-9 tractor size category. Firms in the 2-9 tractor size category, the largest industry size category, are initially expected to lose between 3 and 8 percent of their net income in the near term due to the net effect of industry-wide factors; these impacts should diminish over time, however, as carriers adjust their operations in response to the rule. (See Section 10.3 for further information addressing differential impacts on carriers in different size categories.)

10.2 Results by Option

The PATT Option would adversely impact the net income earned by carriers in every size category, as shown in Exhibit 10-2. This option is the only one that would result in significant adverse impacts on the vast majority of carriers.

In contrast, as shown in Exhibit 10-3 and Exhibit 10-4, respectively, both the ATA Option and the FMCSA Option would result in higher net incomes than in the baseline for carriers in all size categories except one. Under either of these options, firms with 2-9 tractors are expected to face adverse impacts, as discussed in more detail in Section 10.3. Carriers in all size categories would be affected more favorably under the ATA Option than under the FMCSA Option.

Exhibit 10-2
PATT Option: Change in Median Firm Net Income Relative to Baseline

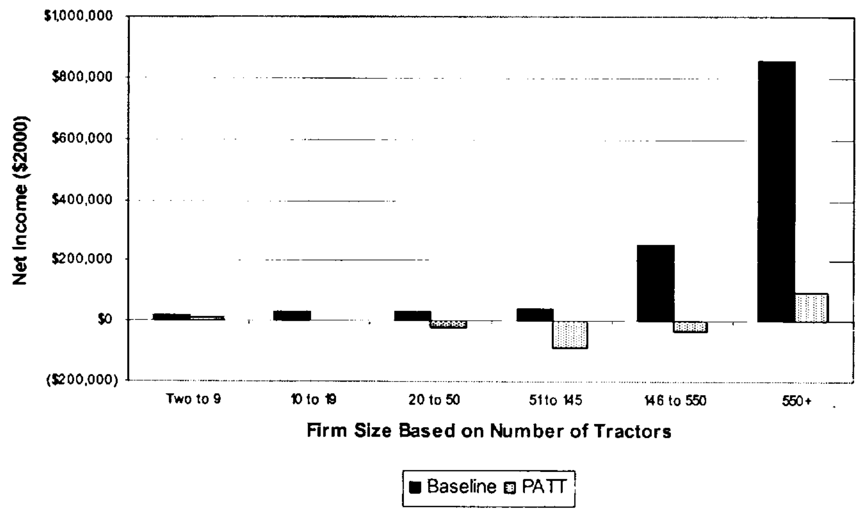


Exhibit 10-3
ATA Option: Change in Median Firm Net Income Relative to Baseline

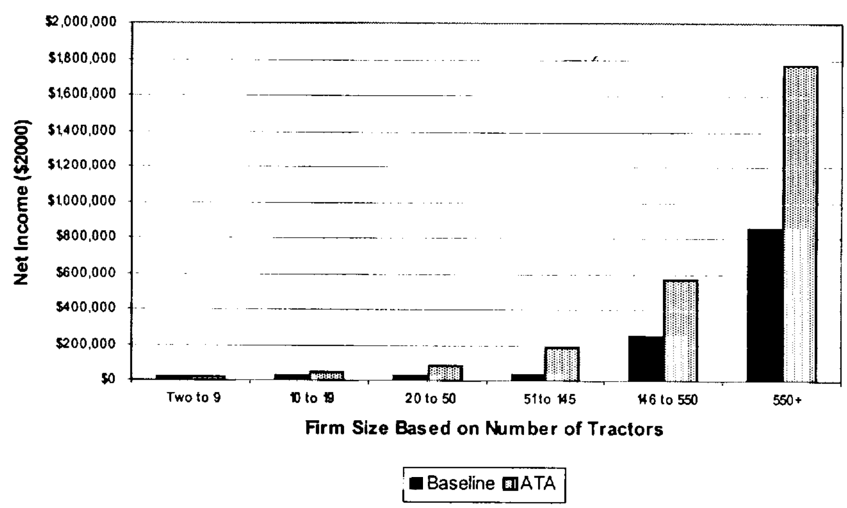
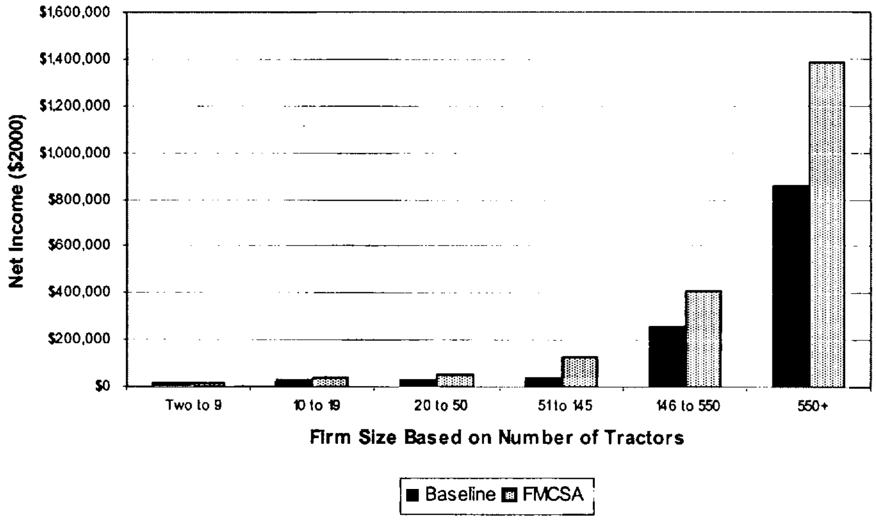


Exhibit 10-4
FMCSA Option: Change in Median Firm Net Income Relative to Baseline



10.3 Differential Impacts: Results by Size Category

This section describes impacts on carriers in the seven size categories. The discussion is divided into three parts: one for owner/operators with one tractor; one for firms with 2-9 tractors; and, because the pattern of impacts is similar for the remaining size categories (10-19 tractors, 20-50 tractors, 51-145 tractors, 146-550 tractors, and 550+ tractors), one for the five largest size categories. As noted earlier, carriers typically exceed the SBA criteria for a small business (annual revenue of $21.5 million or less) when they operate about 145 tractors or more.

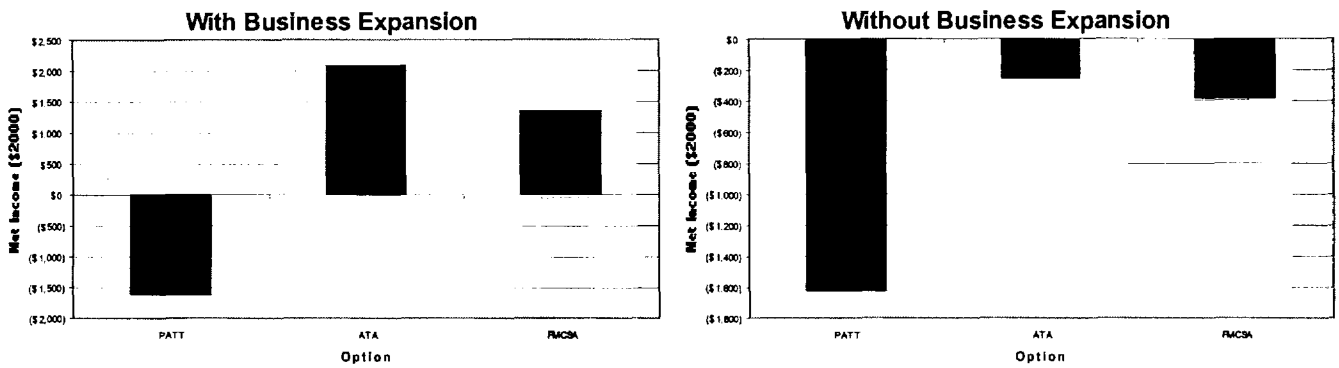
10.3.1 Owner/Operators with 1 Tractor

The smallest size category, one tractor, is examined in order to evaluate impacts on individual owner/operators. Exhibit 10-5 shows the change in net income for these owner/operators under each option, first assuming that owner/operators are able to work as much as allowed by the regulations ("with business expansion") and, alternatively, assuming that they cannot find additional work ("without business expansion") under the ATA or FMCSA Options. This study reports the first assumption ("with business expansion") as the primary result for this size category but presents the alternative assumption as a lower-bound case that may apply in the short term, until owner/operators adjust and generate enough new business to fully-utilize their potential working time.

Assuming business expansion, owner/operators with one tractor would earn less under the PATT option, more under the FMCSA Option, and still more under the ATA Option. (In the short term – i.e., without business expansion – net income initially would fall at an annual rate of between $200 and $400 per carrier under the ATA and FMCSA Options. However, as carriers adjust to the new rules and take on new business, these losses would become income gains of between $1,300 and $2,100.)

Note that the "net income" measured by this study for owner/operators is slightly different in meaning than that for firms in other size categories due to treatment of wages. For owner/operators, net income is the same as take-home pay (analogous to wages). The owner/operator "takes home" any residual after paying all other expenses. In contrast, the net income of larger firms subtracts out wages along with other expenses. Due to this difference, the net income calculated for owner/operators is not directly comparable to that calculated for other firm sizes, and it tends to be higher when stated as a percent of revenue.

Exhibit 10-5
Change in Net Income Per Firm: Owner/Operator (One Tractor/Trailer)



10.3.2 2-9 Tractors

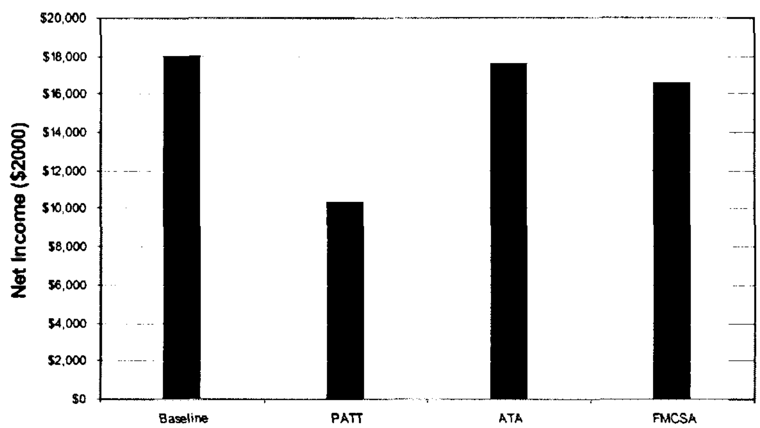
Firms operating 2-9 tractors are in a unique position relative to firms in the other size categories, in that they may have less flexibility to respond to a change in the Hours of Service rules. Whereas larger firms can hire or lay off drivers in order to optimize their operations relative to any of the options, firms with 2-9 tractors are too small to do this in optimal fashion, at least in the near term.[157] For example, under the PATT Option, firms must hire additional drivers in order to maintain their current business. Firms in the 2-9 tractor category, however, do not have enough current business to justify hiring another full-time driver. They would, optimally, hire a fraction of a driver in response to the PATT Option. Assuming this is not possible, these firms must instead sacrifice some of their business, at least in the near term.[158] Similarly, under the ATA or FMCSA Options, these firms optimally would lay off a fraction of a driver. Assuming this is not possible in the near term, then the firms are left with the choice of (1) continuing to service all of their current orders by retaining all drivers (i.e., no change in operations), thereby sacrificing the efficiencies allowed by the rules, or (2) eliminating one driver to in order to increase efficiency, but at the sacrifice of some increment of current business (and the loss of the corresponding revenue).

[157] To a lesser extent this also is true for firms in the 10-19 tractor size category. Firms with 10-19 tractors have enough flexibility, however, that their impacts are similar to (but smaller than) those of firms in larger size categories.

[158] In the longer term, firms should be able to adjust their operations to a greater extent in order to fill capacity, so the impacts on these firms should tend to diminish over time.

As shown in Exhibit 10-6, carriers in this size category are expected to be adversely impacted under any of the three options. Under the PATT Option, these carriers incur a significant adverse impact as a consequence of their inability to meet existing orders and the loss of the corresponding revenues. Near-term impacts under the ATA Option or the FMCSA Option also are expected to be adverse (on average), though in this case carriers would not be expected to alter their operations in the short term; consequently, impacts would result only from the net effect of industry-wide factors (i.e., indirect price and wage effects).[159] The magnitude of the adverse impacts on carriers in this size category would be much less severe under the ATA or FMCSA Options (at an average loss of between 3 and 8 percent of net income) than under the PATT Option (at a loss of 40 percent of net income), and even these small impacts should tend to dissipate over time as firms adjust operations to fill their capacity.

Exhibit 10-6
Net Income Per Firm: 2-9 Tractors



10.3.3 Other Size Categories (10-19 Tractors, 20-50 Tractors 51-145 Tractors, 146-550 Tractors, 550+ Tractors)

Exhibits 10-7 through 10-11 summarize the expected changes in profitability for firms in the remaining five size categories under the three regulatory options. While the direction of the impacts is consistent across all five size categories (i.e., adverse under the PATT Option and favorable under the ATA Option or the FMCSA Option), the magnitude of the impact varies with the size of the firm. In general, larger firms are hurt less (under the PATT Option) or helped more (under either the ATA Option or the FMCSA Option) than are smaller firms.

159 Both the wage rate for drivers and the price of trucking are expected to fall slightly under the ATA Option and the FMCSA Option (and to rise slightly under the PATT Option), as discussed elsewhere in this report. Therefore, revenues will fall slightly due to the price decline and, for carriers with 2-9 tractors, the loss in revenues are offset only by a slight decline in wage rates (there is no change in hours worked).

Exhibit 10-7
Net Income Per Firm: 10-19 Tractors

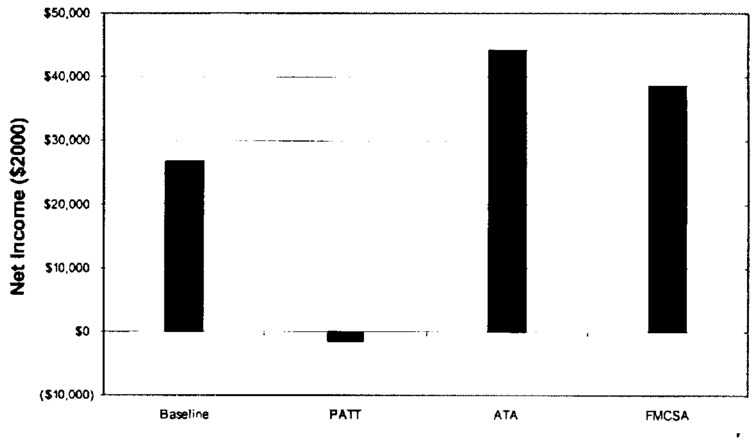


Exhibit 10-8
Net Income Per Firm by Option: 20-50 Tractors

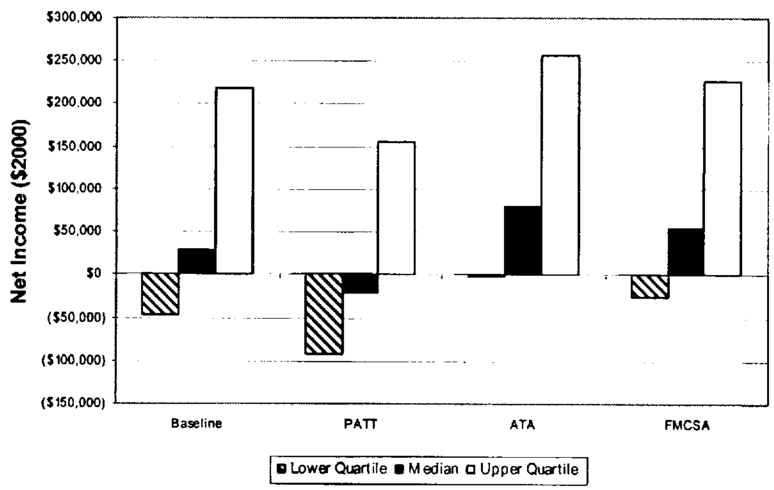


Exhibit 10-9
Net Income Per Firm by Option: 51-145 Tractors

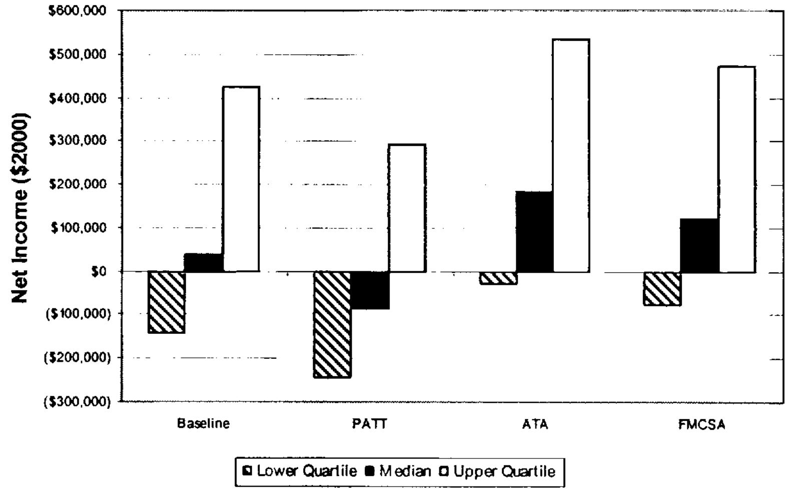


Exhibit 10-10
Net Income Per Firm by Option: 146-550 Tractors

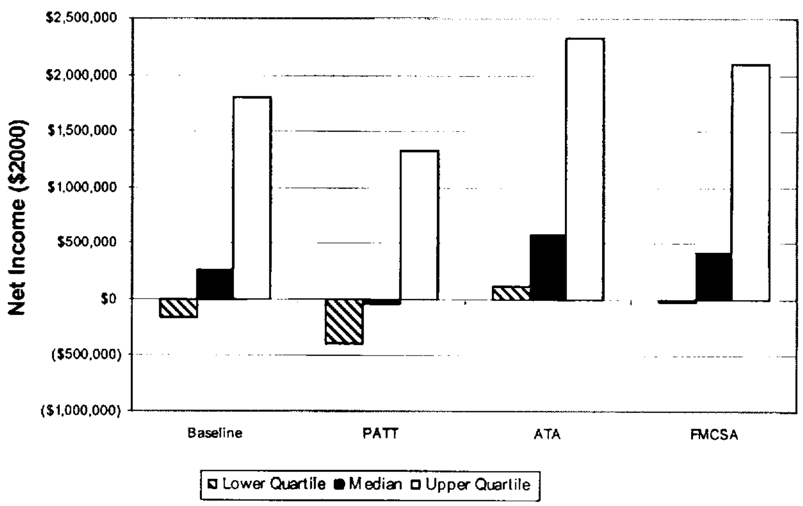
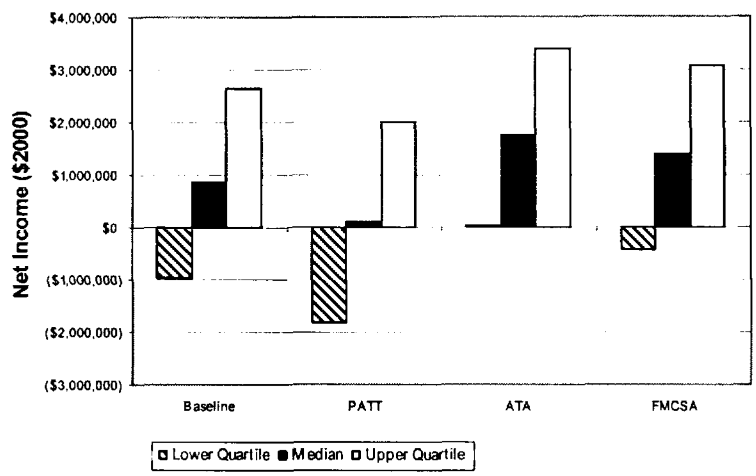


Exhibit 10-11
Net Income Per Firm by Option: 551+ Tractors



11. ECONOMY-WIDE IMPACTS

The proposed Hours of Service (HOS) regulation options under consideration by FMCSA will affect the economy by changing the productivity of labor involved with trucking. The change in labor productivity will affect both for-hire and private carriage trucking activities, where for-hire is associated with the trucking sector and private carriage with sectors having substantial self-provision of trucking services due to the nature of the activity, e.g., wholesale and retail trade, eating and dining establishments, and food manufacturing. An increase (decrease) in labor productivity leads to the need for fewer (more) truckers and related capital and operating costs in the affected sectors in order to achieve the same level of output. Lower (higher) costs lead to lower (higher) prices for trucking services, affecting the competitiveness of trucking relative to rail and resulting in mode shifting. ICF used a 6-region, 53-sector REMI Policy Insight model to estimate the national and regional economic impacts of the proposed policy changes.

11.1 SUMMARY OF RESULTS

The impact of the policy on the overall economy is relatively small, with the change in output never exceeding +/-0.1% based on the output of the REMI Policy Insight model. Exhibit 11-1 reports the 10-year, average annual differences in employment, Gross Regional Product (GRP) – an output measure similar to GDP, price level, and disposable income by proposed rule option by level and percentage change from the full compliance scenario.

Exhibit 11-1
National Economic Impacts by Proposed HOS Rule Option:
Differences in Level and Percent Compared to Full Compliance

Measure	Units	PATT	ATA	FMCSA	Status Quo
Employment	Thousands	-24.9	13.6	7.9	17.9
		-0.01%	0.01%	0.00%	0.01%
GRP	Billion 2000$	-$11.92	$5.69	$3.29	$8.46
		-0.10%	0.05%	0.03%	0.07%
Price Index	Relative. to 2000$	0.28	-0.13	-0.07	-0.21
		0.17%	-0.08%	-0.05%	-0.13%
Disposable Income	Billion 2000$	-$16.16	$7.56	$4.11	$11.51
		-0.19%	0.09%	0.05%	0.14%

Source: ICF analysis.

The PATT option has a negative impact on the overall economy as this option has the greatest decrease in labor productivity based of all the options, with a net average annual employment loss of 24,900 jobs per year, $11.92 billion lower GRP, and $16.16 billion lower disposable income compared to the Full Compliance Base Case. The ATA proposal yields the greatest positive impact on the overall economy due to the policy's positive impact on labor productivity in the trucking sector. The ATA option leads to 13,600 new jobs per year, with a corresponding increase in GRP of $5.69 billion and in disposable income of $7.56 billion/year.

Exhibit 11-2 shows the national employment impacts at the 11-sector level of aggregation to show the relative distribution of impacts across all of the sectors in the economy. The distribution of job impacts suggests that the increase in trucking activity-related employment will pull labor predominantly from the construction, retail trade, and services sectors. The change in overall employment is caused by the impact on the economy of a change in the cost of trucking and wholesale trade on the distribution of goods and services, particularly in manufacturing.

Exhibit 11-2
National Employment Impacts at the 14-Sector Level of Aggregation by Proposed HOS Rule Option: Differences Compared to Full Compliance (Thousands)

Sector	PATT	ATA	FMCSA	Status Quo
Manufacturing	*-19.2*	*9.6*	*5.6*	*13.1*
Durables	-11.2	5.7	3.3	7.6
Non-Durables	-8.0	3.9	2.3	5.5
Non-Manufacturing	*-5.4*	*4.0*	*2.3*	*4.6*
Mining	-0.7	0.4	0.2	0.5
Construction	-17.7	8.4	4.7	12.3
Trans. & Public Utilities	81.6	-38.3	-21.7	-54.1
Fin., Ins., & Real Estate	-6.9	3.5	2.0	5.0
Retail	-37.8	17.5	9.8	25.5
Wholesale	30.3	-14.5	-8.0	-23.0
Services	-52.0	25.8	14.6	36.8
Ag. Services	-2.1	1.1	0.7	1.5
Government	*-0.3*	*0.1*	*0.0*	*0.2*
Totals	-24.9	13.6	7.9	17.9

Source: ICF analysis.

The impact varies by region based on the differences between the region in which truckers are located and the distribution of trucking and wholesale employment by region. These differences lead to differential labor productivity impacts by region in REMI, which will cause differences in the competitiveness of the regions in relation to one another. Exhibit 11-3 summarizes the differences between the regions based on the distribution of drivers and the distribution of trucking sector employment. Exhibit 11-4 shows the regional employment impacts relative to the Full Compliance Base Case. The concentration of drivers in the Rockies/Plains and Northeast regions is greater relative to the other regions. Consequently, the Rockies/Plains and Northeast regions will experience greater benefits from the policy change due to gains in economic competitiveness relative to the other regions.

Exhibit 11-3
Summary of Differences in the Distribution of Drivers vs. Trucking Sector Employment by Region

Region	Share of Drivers	Share of Trucking Employment*	Ratio
Northeast	22%	16%	1.36
Southeast	20%	24%	0.85
Midwest	21%	25%	0.83
South Central	9%	13%	0.74
Rockies/Plains	16%	8%	1.94
Far West	11%	14%	0.81

Source: Current Population Survey from Bureau of Labor Statistics
*Employment based on levels reported in the REMI model

Exhibit 11-4
Regional Employment Impacts
(Thousands)

Region	PATT	ATA	FMCSA	Status Quo
Northeast	-22.9	11.0	6.7	15.9
Southeast	2.9	0.1	0.0	-0.5
Midwest	4.5	-1.5	-0.4	-4.1
South Central	6.7	-3.0	-1.5	-5.0
Rockies/Plains	-23.0	9.0	3.2	15.8
Far West	6.8	-1.9	-0.3	-4.3

Source: ICF analysis

11.2 Modeling Approach

A decrease (increase) in the number of truckers has two direct impacts on the economy, a change in the demand for labor and a change in the demand for trucking-related services. Avoided wages partially offset the impact of changes in the demand for labor, i.e., higher (lower) number of hours worked by existing truckers leads to an increase (decrease) in the avoided wage bill.[160] Lower (higher) demand for employees must be met by laying off (hiring) employees to (from) other sectors in the economy, driving down (up) wages and capital costs.[161]

Fewer (more) truckers will require lower (greater) expenditures on, or demand for, tractor/trailer sets, parking spaces at terminals, truck maintenance, insurance on equipment, and recruiting

[160] See Section 6 for an explanation of how avoided wages are calculated.

[161] ICF used the Anticipatory Fed closure rule in REMI, implying that the Fed will take immediate actions in response to the policy change to maintain the employment-to-labor pool ratio consistent with the modeled NAIRU in REMI. The Anticipatory Fed closure rule is consistent with a closed economy that does not rely on international immigration to meet additional labor requirements, i.e., the change in trucking employment must be met by labor from other sectors. This assumption is similar to that made by Belzer (2002).

services.[162] Changes in capital expenditures associated with tractor/trailer sets and parking space construction are financed out of consumption at an assumed cost of capital to accommodate the "lumpy" nature of the changes in investments over time.

The aggregation of the change in labor and trucking-related costs is an input to an analysis of the competitiveness of trucking versus rail. The elasticity of the change in demand for trucking and rail transportation with respect to a change in the price of trucking is used to estimate the effects of mode shifting by shippers.[163] The mode shift analysis estimates the anticipated increase (decrease) in demand for trucking and corresponding decrease (increase) in rail transportation.

The primary benefit from a change in hours of service regulations pertains to the change in road safety and the corresponding change in payouts by the insurance sector to cover the costs. ICF assumed that the insurance companies only pass back a portion of the lower premiums directly to trucking companies based on discussions with its industry analysts. The rest of the change in insurance premiums is assumed to be shared among non-trucking firms and consumers through lower prices as insurance sector production costs decrease for purposes of the regional economic analysis.[164]

11.3 Application of REMI to Proposed HOS Policies

ICF used a six-region, 53-sector version of the REMI Policy Insight model (Regional Economic Modeling Inc.) to analyze the regional economic impacts.[165] The economic analysis should allow for the demonstration of differential regional impacts by sector based on each region's relative reliance upon trucking and intermodal transportation. The United States is broken out into six regions for purposes of this analysis in an attempt to model these relative differences, as shown in Exhibit 11-5. A graphical depiction of the regions is shown in Exhibit 11-6, where major highways and U.S. cities have been overlaid to show the relationships between the regions and the major hubs and transportation corridors.

Exhibit 11-5
Regions for Modeling Using REMI

Northeast	Southeast	Midwest	South Central	Plains/Rockies	Far West
Connecticut	Alabama	Illinois	Arkansas	Arizona	Alaska
Delaware	Florida	Indiana	Louisiana	Colorado	California
Maine	Georgia	Iowa	Oklahoma	Idaho	Hawaii
Maryland	Kentucky	Michigan	Texas	Kansas	Nevada
Massachusetts	Mississippi	Missouri		Montana	Oregon
New	North Carolina	Minnesota		Nebraska	Washington

[162] See Chapter 6 for an explanation of the estimation techniques used to determine these costs. Note that the decrease (increase) in tractor/trailer sets is offset over time to a large degree by a direct decrease (increase) in the average useful life of the existing fleet.

[163] See Chapter 7 and Appendix D for an explanation of the mode shift analysis. Note that the industry is assumed to be competitive and that all costs will necessarily be passed as higher prices for trucking services. Also, the entire impact of the mode shift accrues to the trucking sector in this analysis.

[164] ICF assumed a ratio of 50/50 for distribution of benefits between the trucking and insurance sectors.

[165] For an overview of REMI Policy Insight, refer to Appendix I, or go to www.remi.com.

Northeast	Southeast	Midwest	South Central	Plains/Rockies	Far West
Hampshire New Jersey New York Pennsylvania Rhode Island Vermont District of Col.	South Carolina Tennessee Virginia West Virginia	Ohio Wisconsin		New Mexico North Dakota South Dakota Utah Wyoming	

Exhibit 11-7 summarizes the flow of impacts beginning with the change in the policy through the direct impacts on trucking, trucking-related, and mode shift-affected sectors (based on the discussion in Section 11.2) to the input into REMI policy variables. Care must be taken in mapping the impacts to policy variables to avoid introducing arbitrary changes that fail to take into account the source and destination of an impact. For example, if a change in demand for insurance is modeled without a corresponding increase in production costs in the affected sectors, the economy would be artificially stimulated. The dashed-arrows are used to show off-setting or complementary flows relative to a change in the demand for a specific sector that is not offset within REMI. The REMI policy variables are explained in the text box following Exhibit 11-7.

Exhibit 11-6
Map of Regions for Modeling Using REMI

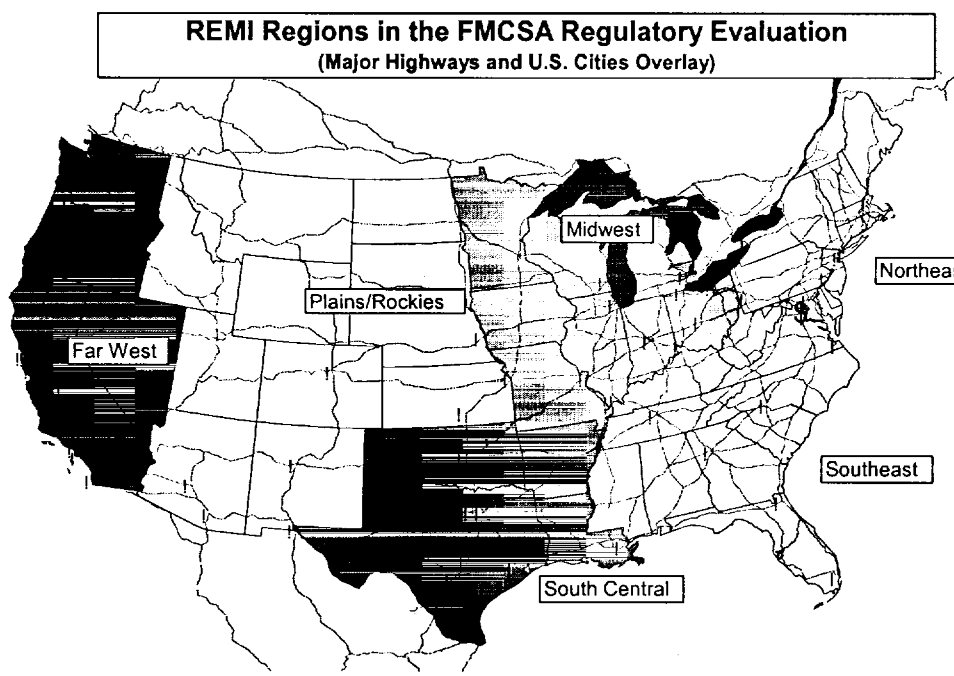
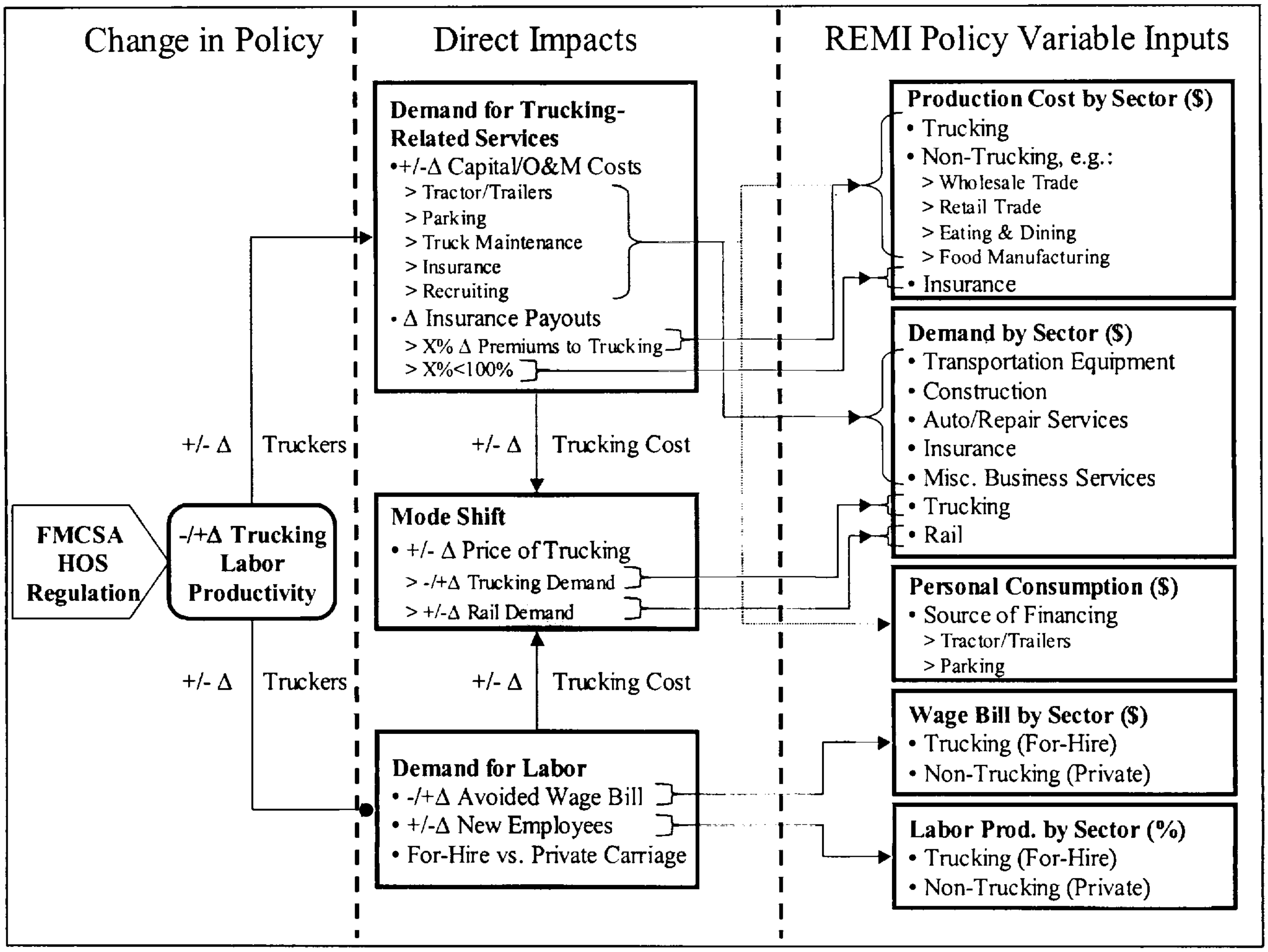


Exhibit 11-7
Mapping of Policy Impacts to REMI Policy Variable Inputs



A key concept for analyzing the results of the analysis lies with the classification in REMI of industries as either national or regional. The transportation sectors are generally treated as regional industries, i.e., competition is among firms within the region, meaning that any increase in the sector's production costs must be recovered from customers in the form of higher prices. Conversely, national industries compete with firms/prices, in national markets, where changes in costs are generally not recoverable through higher prices due to the exposure to the national markets resulting in lower profits to the sector.

Changes in the output or employment in one sector will also affect labor markets and demographic patterns in the long-term. As output or employment increase in a sector, the labor is attracted from other sectors and pressure is also placed on the regional consumer price index, both factors leading to an increase in relative wage rates. In the longer-term, changes in relative wage rates between regions will affect regional migration patterns and population trends, increasing the labor pool in the region and offsetting some of the wage growth. Conversely, firms that compete nationally will experience lower profits and lower output. Consumers will be adversely affected by higher prices for goods and services. These latter effects will tend to offset output from the initial stimulus and the corresponding increase in relative regional wages.

The anticipated impact on employment in the trucking sector during the first few years will be positive to reflect the need for more employees to deliver the same amount of output. However, as regional trucking prices increase in response to the change in overall production costs, the output of sectors in the each regional economy will be adversely affected gradually over a five to ten-year time horizon. Manufacturing firms in the region that compete nationally will face lower profitability while firms selling services will have to pass higher production costs on to consumers, squeezing household budgets. The sensitivity of each region to higher trucking costs will depend on the region's relative degree of dependence by sectors in the region on trucking services. Eventually, the decrease in regional output will feed back onto the trucking sector, resulting in lower demand (and employment) in the sector.

Formal Definition of REMI Policy Variables*

Production Cost (amount) policy variables change the Relative Production Costs of the specified industry by the proportion or percentage of total industry Output (or the amount) entered. They should be used when a specific policy will affect the cost of doing business in a region without directly changing the relative costs of factor inputs (labor, capital, and/or fuel). *Relative Production Costs* are defined as the costs of producing goods and services for a regional industry relative to the US; depends on relative factor productivity, relative factor costs, and material input costs.

Demand (amount) policy variables change the total Demand in the specified industry. For policy variables which affect demand, only the proportion of demand that is usually supplied locally is added to local production. The remainder of the amount that you enter is assumed to be produced elsewhere and imported to the area. *Translator Variables* (amount) are used to convert expenditure changes for detailed producer's durable equipment policy variable(s) within the Transportation Equipment Spending (amount) and Construction (amount) categories into the appropriate change in exogenous local Industry Demand using the technical coefficients from a more detailed Input/Output Matrix. These variables should be used to change specific Investment Spending for the region.

Consumer Expenditure Price Index (equivalent dollar amount) policy variable changes the *Consumer Expenditure Price Index* through a conversion of the dollar amount entered. The dollar amount represents the change in consumer purchasing power. A positive dollar amount represents a LOSS in purchasing power (or increase in the price index), and vice-versa. This variable should be used to simulate any policy that reduces real disposable income to consumers without changing relative commodity prices (or assuming a price elasticity of 0).

Wage Bill (amount) policy variables change the *Wage Bill* within the specified industry by the dollar amount entered. This takes into account that employees in individual firms may have a different wage rate than REMI's calculated industry average wage. These variables should be used to adjust the wage and salary disbursements associated with exogenous employment changes without changing the wage rate for all employees within a given industry.

Labor Productivity (share) policy variables change the level of Labor Productivity in the specified industry by the proportion or percentage entered. It should be used when output per unit of labor is expected to change, and will result in substitution between the factors of production.

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*Definitions taken from the REMI Help System designed by Ronald S. Miller for Regional Economic Models, Inc.; Revisions and additions by Julie Lind Ervin. Additional editing has been performed to improve readability.

12. BIBLIOGRAPHY

1. Abrams C., Schultz, T., and Wylie, C.D. (1997). "Commercial Motor Vehicle Driver Fatigue, Alertness, and Countermeasures Survey," U.S. Department of Transportation, Federal Highway Administration, August.

2. Akerstedt, T. & Folkard, S. (1997). "The three-process model of alertness and its extension to performance, sleep latency, and sleep length," *Chronobiology International* Vol. 14, No. 2. pp 115-123.

3. Akerstedt, T. (1997). Available countermeasures against operator fatigue. In: Rogers, W. C. (Ed.) International Conference Proceedings on Managing Fatigue in Transportation, Tampa, FL, April 1997.

4. Akerstedt, T., (1988). "Sleepiness as a consequence of shift work" *Sleep*, 11, 17-34

5. Akerstedt, T., Gillberg, M, (1981). "The circadian variation of experimentally displaced sleep," *Sleep,* 4: 159-169.

6. Akerstedt, T., Gillberg, M., (1982). "Displacement of the sleep period and sleep deprivation: implications for shift work," *Human Neurobiology*, 1, 163-171.

7. Akerstedt, T., Gillberg, M., Torscall, L, Froberg, J., (1980). Reports from the Laboratory for Clinical Stress Research, No 132. In Akerstedt, T., Gillberg, M., 1982. "Displacement of the sleep period and sleep deprivation: implications for shift work," *Human Neurobiology* 1, 163-171.

8. Akerstedt, T., Kecklund, G., Knutsson, A., (1981). "Manifest sleepiness and the spectral content of the EEG during shift work," *Sleep,* 14, 221-225.

9. Akerstedt, T., Levi, L., (1978). "Circadian rhythms in the secretion of cortisol, adrenaline and noradrenaline," *European Journal of Clinical Investigation*, 8, 57-58.

10. Alluisi, E.A. & Morgan, B.B. (1982). Temporal factors in human performance and productivity. In E.A. Alluisi & E. A. Fleishman (Eds.) *Human performance and productivity.* Hillsdale, NJ: Lawrence Erlbaum Associates.

11. American Automobile Association (AAA) Foundation for Traffic Safety (1985). A report on the determination and evaluation of the role of fatigue in heavy truck accidents. Washington, DC: Transportation Research and Marketing.

12. American Trucking Associations. (2000). *North American Truck Fleet Directory.*

13. Angus, R.G. & Heslegrave, R.J. (1985). "Effects of sleep loss on sustained cognitive performance during a command and control simulation," *Behavior Research Methods, Instruments, & Computers,* Vol. 17, No.1, pp 55-67.

14. Ault, R.W. and Ekelund, R.B. "Public Interest Comment on the Department of Transportation's Proposed Rules: Hours of Service Drivers; Driver Rest and Sleep for Safe Operations," Regulatory Studies Program, Mercatus Center, George Mason University. FMCSA-97-2350-23248. No date.

15. Babkoff, H. Thorne, D.R., Sing, H.C., Genser, S.G., Taube, S.L., & Hegge, F. W. (1985). "Dynamic changes in work-rest duty cycles in a study of sleep deprivation," *Behavior Research Methods, Instruments, & Computers*, Vol. 17, No. 6, pp 604-613.

16. Babkoff, H., Genser, S.G., Sing, H.C., Thorne, D.R. & Hegge, F.W. (1985). "The effects of progressive sleep loss on a lexical decision task: Response lapses and response accuracy," *Behavior Research Methods, Instruments, & Computers*, Vol. 17, No. 6, pp 614-622.

17. Babkoff, H., Mikulincer, M., Caspy, T., Carasso, R.L., & Sing, H.C. (1989). "The implications of sleep loss for circadian performance accuracy," *Work & Stress*, Vol. 3, pp 3-14.

18. Balkin, T. J., Thorne, D., Sing, H., Thomas, M., Redmond, D.P., Wesensten, N., Russo, M., Williams, J., Hall, S., & Belenky, G.L. Effects of sleep schedules on commercial motor vehicle driver performance. Washington, DC: US Dept. of Transportation, Federal Motor Carrier Safety Administration, Report No. DOT-MC-00-133, May 2000.

19. Balkin, T., Thome, D., Sing, H., Thomas, M., Redmond, D., Wesensten, N., Williams, J., Hall, S., and Belenky, G. (2000). "Effects of Sleep Schedules on Commercial Motor Vehicle Driver Performance," Walter Reed Army Institute of Research, Washington, D.C. 2000. FMCSA Docket No. 2000-2350-2010.

20. Beilock, R. (1989). 1988 RCCC Motor Carrier Safety Survey. Alexandria, VA: Regular Common Carrier Conference.

21. Belman, D. University of Michigan Trucking Industry Program (UMTIP) Driver Surveys (1997-1999), the University of Michigan Institute for Social Research.

22. Belman, D., Monaco, K., and Brooks, T. (1998). "Let it Be Palletized: A Portrait of Truck Drivers' Work and Lives," University of Michigan Trucking Industry Program.

23. Belzer, M. (1995). "Collective Bargaining after Deregulation: Do the Teamsters Still Count?" *Industrial & Labor Relations Review*, 48(4), 636-655.

24. Belzer, M. (1999). "Hours of Service Impact Assessment," University of Michigan Transportation Research Institute, March.

25. Belzer, M., *et al.* (2002). "Pay for Safety: An Economic Alternative for Truck Driver Safety," FMCSA, Forthcoming.

26. Berkman, M., David, J., Liu, M., and Pan, A. (2000). "A Review of the Federal Motor Carrier Safety Administration's Economic Analysis for its Proposed Hours of Service Standard," Prepared for the American Trucking Association by National Economic Research Associates (NERA). August.

27. Bonnet, M.H., Arand, D.L., (1995). "We are chronically sleep deprived," *Sleep,* 18 (10), 908-911.

28. Borbely A.A., Achermann P. (1992). "Concepts and Models of Sleep Regulation: an overview," *Journal of Sleep Research,* 1(1), pg. 63.

29. Braver, E., Preusser, C., Preusser, D., Baum, H., Beilock, R., and Ulmer, R. (1992). "Who Violates Work-Hour Rules? A Survey of Tractor-Trailer Drivers," Insurance Institute for Highway Safety FMCSA Docket No. 1992-2350-273.

30. Caldwell, J.L., Gilreath, D.S., (2000). A survey of subjective sleep length of shift workers based on time of day of sleep onset. Presented at the 14th Annual Meeting of the Associated Professional Sleep Societies.

31. Czeisler, C.A., Weitzman, E.D., Moore-Ede, M.C., Zimmerman, J.C., Knauer, R.S., (1980). "Human sleep: its duration and organization depend on its circadian phase," *Science*, 210, 1264-1267.

32. Czeisler, C.A., Zimmerman, J.C., Ronda, J.M., Moore-Ede, M.C., Weitzman, E.D., (1980). "Timing of REM sleep is coupled to the circadian rhythm of body temperature in man," *Sleep,* 2: 329-346.

33. Dijk D-J, Czeisler CA., (1996). "Bimodal distribution of REM sleep latency during forced desynchrony: model implications," *Journal of Sleep Research,* 25: 122.

34. Dijk, DJ. et al., (1992). "Circadian and sleep/wake dependent aspects of subjective alertness and cognitive performance," *Journal of Sleep Research*, 1:112117.

35. Dinges, D.F. & Powell, J.W. (1985). "Microcomputer analyses of performance on a portable, simple reaction time task during sustained operations," *Behavior Research Methods, Instruments & Computers*, Vol. 17, No. 6, 652-655.

36. Dinges, D.F., Kribbs, N.B., (1991). Performing while sleepy: effects of experimentally induced sleepiness. In Monk, T. (ed.) *Sleep, sleepiness and performance.* New York: John Wiley & Sons.

37. Dinges, D.F., Mallis, M., Maislin, G., Powell, J.W. (1998). Evaluation of techniques for ocular measurement as an index of fatigue and the basis for alertness management. Washington, DC: US Department of Transportation, National Highway Traffic Safety Administration (University of Pennsylvania Contract submission technical report).

38. Dinges, D.F., Orne, M.T., Whitehouse, W. G., & Orne, E.C. (1987). "Temporal placement of a nap for alertness: Contributions of circadian phase and prior wakefulness," *Sleep* Vol. 10, pp 313-329.

39. Distribution and LTL Carriers Association. (2000). Comment on "Hours of Service of Drivers; Driver Rest and Sleep for Safe Operations," FMCSA Docket No. 1997-2350-20928, June.

40. Eberts, R.W. and Stone, J.A. (1992). "Wage and Employment Adjustment in Local Labor Markets," W.E. Upjohn Institute.

41. Ellingstad, V.S. & Heimstra, N. W. (1970). "Performance changes during the sustained operation of a complex psychomotor task," *Ergonomics*, Vol. 13, pp 693-705.

42. Engel, C. (1998). "Competition Drives the Trucking Industry," *Monthly Labor Review*, April 34-41.

43. Englund, C.E., & Krueger, G.P. "Methodological approaches to the study of sustained work-sustained operations: Introduction to a special section," *Behavior Research Methods, Instruments & Computers*, 1985, 17(1), 3-5.

44. Feenberg, D. and Roth, J. (2002). *Current Population Survey Labor Extracts 1979-2001*, National Bureau of Economic Research, January.

45. Fletcher A., (2002). A Discussion of Fatigue and Risk management. Centre for Sleep Research, University of South Australia.

46. Fletcher, A. & Dawson, D. (2000). Field-based validations of a work-related fatigue model based on hours of work. Paper presented at the 4th International Conference on Managing Fatigue in Transportation, Freemantle, Western Australia, March, 2000.

47. Folkard, S., (1997). "Black times: temporal determinants of transport safety," *Accident Analysis and Prevention* 29 (4), 417-430.

48. Folkard, S., Akerstedt, T., Macdonald, I., Tucker, P., & Spencer, M.B. (1999). "Beyond the three-process model of alertness: Estimating phase, time on shift and successive night effects," *Journal of Biological Rhythms*, Vol. 14, No. 6, pp 577-587.

49. Frith, W.J., (1994). A case control study of heavy vehicle drivers' working time and safety. Victoria, Australia: Proceedings, 17th Australian Road Research Board Conference, Part 5, 17-30.

50. Gillberg, M., Akerstedt, T. (1998). "Sleep loss and performance: no "safe" duration of a monotonous task," *Physiology and Behavior,* 64(5), 599-604.

51. Gold, D.R., et al., (1992). "Rotating shift work, sleep and accidents related to sleepiness in hospital nurses," *American Journal of Public Health*, 82 (7), 1011-1014.

52. Greene, W. (1993). *Econometric Analysis*, Macmillan Publishing, Ch 16 section 4.

53. Griffin, G.C. and Rodriguez, J.M. (1990). "The Determinants of Job Satisfaction of Professional Drivers," *Journal of the Transportation Research Forum*, 2, pp. 453-464.

54. Hanowski, R., Wierwille, W., Garness, A., Early, N., and Dingus, T. (2000). "Impact of Local/Short Haul Operations on Driver Fatigue, Task 2: Field Study," Center for Transportation Research, Virginia Polytechnic Institute and State University, FMCSA Docket No. 1997-2350-621.

55. Harris, W., (1978). Fatigue, circadian rhythm, and truck accidents in ed. Mackie, R. *Vigilance: Theory, Operational Performance and Physiological Correlates.* New York, NY: Plenum Press, 133-146.

56. Hartley, L., Horberry, T., Mabbott, N. & Krueger, G.P. (2000). Review of fatigue detection and prediction technologies._ Melbourne, Australia: Australian National Road Transport Commission Technical Report, Sept. 2000.

57. Haslam, D.R. & Abraham, P. (1987). Sleep loss and military performance. In: G.L. Belenky (Ed.) *Contemporary studies in combat psychiatry.* New York: Greenwood Press. 167-184.

58. Haslam, D.R. (1982). "Sleep loss, recovery sleep and military performance," *Ergonomics*, Vol. 25 pp 163-178.

59. Hertz, R.P., (1988). "Tractor-trailer driver fatality: the role of nonconnective rest in a sleep berth," *Accident Analysis and Prevention*, 20 (6), 429-431.

60. Hirsch, B.T. (1988). "Trucking Regulation, Unionization and Labor Earnings: 1973-85," *Journal of Human Resources*, Vol. 23, No. 3, pp. 296-319.

61. Hirsch, B.T. (1993). "Trucking Deregulation and Labor Earnings: Is the Union Premium a Compensating Differential?" *Journal of Labor Economics.* Vol 11. No. 2. pp. 279-301.

62. Hursh, S. R., Balkin, T. J., Belenky, G. L., Eddy, D.R., Hurtle, W. R., Johnson, M. L., Mitler, J.C., Redmond, D.P., Storm, W. F., and Thorne, D. R. (2002). DOD fatigue models for applied research in warfighting. Presentation at the Seattle, WA workshop on sleep and performance modeling, May.

63. Imus, S. National Association of Truck Stop Owners, http://www.natso.com/for_members/government_downloads/truckparking_solutions2001.doc.

64. International Parking Institute. "Frequently Asked Questions." http://www.parking.org/main/faq.htm.

65. Jewett ME, Dijk D-J, Kronauer RE, Czeisler CA. (1996), "Homeostatic and circadian components of subjective alertness interact in a non-additive manner," *Journal of Sleep Research*, 1996; 25: 555.

66. Jha, A.K., Duncan, B.W., Bates, D.W., (2001). Fatigue, Sleepiness and Medical Errors, for the Agency for Health Care Research and Quality.

67. Jones, I.S. & Stein, H.S. (1987). Effect of driver hours of service on tractor-trailer crash involvement. (Proceedings paper). Arlington, VA: Insurance Institute for Highway Safety.

68. Jovanis, P.P, Kaneko, T., Lin, T.D., (1991). Exploratory analysis of motor carrier accident risk and daily driving patterns. 70th Annual Meeting of Transportation Research Board, Transportation Research Board, Washington, DC.

69. Kaneko, T., Jovanis, P., (1992). "Multiday driving patterns and motor carrier accident risk: a disaggregate analysis," *Accident Analysis and Prevention* 24 (5), 437-452.

70. Kecklund, G., Akerstedt, T., (1995). Time of day and Swedish road accidents. Shiftwork International Newsletter 12 (1).

71. Knipling, R. R. & Wang, J.S. (1994). Crashes and fatalities related to driver drowsiness/fatigue. (Research Note). Washington, DC: National Highway Traffic Safety Administration.

72. Knipling, R.R. & Wang, J.S. (1995). Revised estimates of the U.S. drowsy driver crash problem size based on general estimates system case reviews. 39th Annual Proceedings, Association for the Advancement of Automotive Medicine, Chicago, IL.

73. Koslowsky, M., Babkoff, H., (1992). "Meta-analysis of the relationship between total sleep deprivation and performance," *Chronobiology International*, 9, 132-136.

74. Kribbs, N.B. & Dinges, D.F. (1994). Vigilance decrement and sleepiness. In Harsh, J.R. & Ogilve, R.D. (eds.) *Sleep onset mechanisms*. Washington, DC: American Psychological Association, 113-125.

75. Krueger, G. P. (1991) Sustained military performance in continuous operations: Combatant fatigue, rest and sleep needs. In: Gal , R. & Mangelsdorff, A.D. (Eds.) *Handbook of Military Psychology* 255-277. Chichester, UK: Wiley & Sons. Also as USAARL Technical Report No. 91-19, U.S. Army Aeromedical Research Laboratory, Fort Rucker, AL, September, 1991. (DTIC No. AD: A242-507).

76. Krueger, G.P (1989). Sustained work, fatigue, sleep loss and performance: A review of the issues. *Work & Stress*, 3(2), 129-141. (Also as USAARL Tech Rep 89-22). Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory, September 1989. (DTIC No. AD: A215-234).

77. Krueger, G.P, & Van Hemel, S.B. (2001). Effects of loading and unloading cargo on commercial truck driver alertness and performance. Federal Motor Carrier Safety Administration FMCSA Technical Report No. DOT-MC-01-107 (May 2001). Washington, DC: US Department of Transportation.

78. Krueger, G.P. & Englund, C.E. (1985). "Methodological approaches to the study of sustained work/sustained operations: Introduction to 2nd special section," *Behavior Research Methods, Instruments & Computers*, 17(6), 587-591.

79. Lavie, P.(1986). "Ultrashort sleep-waking schedule, III. 'Gates' and 'forbidden zones' for sleep," *Electroencephalography and Clinical Neurophysiology*, 63, 414-425.

80. Lettau, M.K. (1994). "Wage Adjustments in Local Labor Markets: Do the Wage Rates in all Industries Adjust?" Office of Economic Research, Bureau of Labor Statistics. May.

81. Lin, T.D., Jovanis, P.P., Yang, C.Z., (1994). Time of day models of motor carrier accident risk, Transportation Research Record 1457, National Academy Press, Washington, DC.

82. Lin, T-D., Jovanis, P.P. & Yang, C-Z. (1993) Modeling the safety of truck driver service hours using time-dependent logistic regression. Transportation Research Record, 1407 1-10.

83. Mackie, R.R. & Miller, J.C. (1978). Effects of hours of service, regularity of schedules, and cargo loading on truck and bus driver fatigue. (NHTSA Technical Report No. DOT-HS-803-799). Goleta, CA: Human Factors Research, Inc. (NTIS No. PB-290-957).

84. Mackie, R.R., Miller, J.C., (1980). Effects of irregular schedules and physical work on commercial driver fatigue and performance. *Human Factors in Transport Research*. London, UK: Academic Press Inc.

85. Manber, R., Bootzin, R., (1991). "The effects of regular wake-up schedules on daytime sleepiness in college students," *Sleep Research*, 20, 284.

86. Massie, D., Blower, D., and Campbell, K. (1997). "Short-Haul Trucks and Driver Fatigue." Report No. FHWA-MC-1997-98-016, September.

87. McCartt, A., Hammer, M., and Fuller, S. (1998). "Study of Fatigue-Related Driving Among Long-Distance Truck Drivers in New York State, Volume 1: Survey of Long-Distance Truck Drivers," Institute for Traffic Safety Management and Research.

88. McCartt, A.T., Rohrbaugh, H.W., Hammer, M.C., Fuller, S.Z., (2000). "Factors associated with falling asleep at the wheel among long-distance truck drivers," *Accident Analysis and Prevention*, 32, 493-504.

89. Mitler, M.M., Carskadon, M.A., Czeisler, C.S., Dement, W.C., Dinges, D.F., Graeber, R.C., (1988). "Catastrophes, sleep and public policy," *Sleep*, 11 (1), 100-109.

90. Monk, T.H., Folkard, S., (1979). "Shiftwork and performance," *Human Factors* 21 (4), 483-492.

91. National Transportation Safety Board (1990). Safety study: Fatigue, alcohol, other drugs, and medical factors in fatal-to-the-driver heavy truck crashes (Volume 1). NTSB Report No. SS-90-01. Washington, DC: National Transportation Safety Board.

92. National Transportation Safety Board (1995). Factors that affect fatigue in heavy truck accidents. Volume 1: Analysis; Volume 2: Case summaries. Washington, DC: National Transportation Safety Board.

93. O'Neill, T.R., Krueger, G.P., Van Hemel, S.B., & McGowan, A.L. (1999). Effects of operating practices on commercial driver alertness. (FHWA-OMC Technical Report No. FHWA-MC-99-140.) Washington DC: U.S. Department of Transportation.

94. O'Neill, T.R., Krueger, G.P., Van Hemel, S.B., McGowan, A.L., & Rogers, W.C. (1999). Effects of cargo loading and unloading on truck driver alertness. National Research Council Transportation Research Record 1686, Paper No. 99-0789; pg. 42-48.

95. Penneau, B. and Smits, R. (1997). *What Matters to Drivers*, J. J. Keller & Associates, Inc., December.

96. Pilcher, J.J., Huffcutt, A.I., (1996). "Effects of sleep deprivation on performance: a meta-analysis," *Sleep*, 19, 318-326.

97. Private Carrier Proprietary Route Information. (2002) Acquired by Eric Beshers, Independent Contractor, ICF Consulting.

98. Risk Management Association. *Annual Statement Studies*. 2001-2002 edition CD-ROM Version 4.1. No date.

99. Rodriguez, J., M. Kosir, B. Lantz, Griffen, G., and Glatt, J. (2000). "The Costs of Truckload Driver Turnover," Upper Great Plains Transportation Institute, North Dakota State University, April.

100. Rose, N. (1987). "Labor Rent Sharing and Regulation: Evidence from the Trucking Industry," *Journal of Political Economy*, 95.

101. Rosekind, M.R., Graeber, R.C., Dinges, D.F. et al. (1994). Crew factors in flight operations: IX. Effects of cockpit rest on crew performance and alertness in long-haul operations. (NASA Technical Memorandum Report No. 103884, 252 pages.) Moffitt Field, CA: NASA Ames Research Center.

102. Saccomanno, F.F., Yu, M., and Shortreed, J.H., (1995). Effect of driver fatigue on truck accident rates. Urban Transport and the Environment for the 21st Century, ed. Sucharov, L.J., Southampton, UK: Computational Mechanics Publications, 439-446.

103. Seeley, J. M. "Site Design Guidelines: Rules of Thumbs for Sites," http://www.fsfarchitects.com/ExtGuide.htm.

104. Siebert, J. (2001). Comments for Session 236, 2001 TRB Annual Meeting, January.

105. The Gallup Organization for ATA Foundation. (1997). "Empty Seats and Musical Chairs: Critical Success Factors in Truck Driver Retention," October.

106. Thorne, D. R., Genser, S. G., Sing, H.C. & Hegge, F.W. (1985). "The Walter Reed performance assessment battery," *Neurobehavioral Toxicology and Teratology*, Vol. 7, pp 415-418.

107. Transportation Technical Services Inc. (2002). *National Motor Carrier Directory*.

108. Transportation Technical Services, Inc. (1999). *America's Private Carriers.*

109. Transportation Technical Services, Inc. (2001). *The Motor Carrier Industry in Transition.*

110. Transportation Technical Services, Inc. *Blue Book of the Trucking Companies*, 2001-2002 edition CD-ROM. No date.

111. Treyz, G. I. (1993). *Regional Economic Modeling: A Systematic Approach to Economic Forecasting and Policy Analysis*, Norwell, MA: Kluwer Academic Publishers.

112. U.S. Census, Commodity Flow Survey. (1997).

113. U.S. Census, Economic Census of the United States (2000).

114. U.S. Census, Economic Census of the United States (1997).

115. U.S. Census, Vehicle Inventory and Use Survey (1997).

116. U.S. Department of Transportation, Federal Highway Administration. (1996). "Commercial Driver Rest & Parking Requirements: Making Space for Safety – Final Report." Report No. FHWA-MC-96-0010, May, Table III-2, p. 97.

117. U.S. Department of Transportation, Federal Highway Administration, FHWA, Office of Motor Carrier & Highway Safety (OMCHS). (1999). "Effects of Operating Practices on Commercial Driver Alertness." NTIS NO. PB 2000-100799.

118. U.S. Department of Transportation, Federal Motor Carrier Safety Administration. (1999). Motor Carrier Management Information System Census File. Merrifield, VA: Computing Technologies, Inc., March.

119. U.S. Department of Transportation, Federal Motor Carrier Safety Administration. (2000). "Preliminary Regulatory Evaluation and Regulatory Flexibility Act Analysis Hours of Service NPRM," April, FMCSA Docket No. 1997-2350-954.

120. U.S. Department of Transportation, Federal Motor Carrier Safety Administration. (2001). Inspections and Violations Databases.

121. Williams, H.L. and Lubin, A. (1967). "Speeded addition and sleep loss," *Journal of Experimental Psychology*, Vol. 73, pp 313-317.

122. Williams, H.L., Lubin, A. & Goodnow, J.J. (1959). "Impaired performance with acute sleep loss," *Psychological Monographs*, Vol 73, No. 14, Whole Monograph No. 484, pp 1-26.

123. Williamson, A.M., Feyer, A.M., Friswell, R., (1996). "The impact of work practices on fatigue in long distance truck drivers," *Accident Analysis and Prevention*, 28 (6), 709-719.

124. Wylie, C.D., Shultz, T., Miller, J.C., Mitler, M.M. & Mackie, R.R. (1996). Commercial motor vehicle driver fatigue and alertness study. (FHWA Technical Report No. MC-97-002). Washington, DC: Federal Highway Administration, U.S. Department of Transportation.

125. Zaloshnja E., Miller T., Spicer R. (2000). "Costs of Large Truck-and-Bus Involved Crashes," October. Washington, D.C., U.S. Department of Transportation.

REGULATORY IMPACT ANALYSIS AND SMALL BUSINESS ANALYSIS FOR HOURS OF SERVICE OPTIONS

APPENDICES

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APPENDIX A.
DETAILED DATA AND DESCRIPTION OF ESTIMATE METHODS

This section contains our estimates of the number of for-hire trucking companies, their revenues, the number of tractors they use, and distribution of these numbers across several size and area of operations (average length of haul) categories. It also contains estimates of truck VMT and of the number of drivers engaged in long-haul TL and private service

We estimate that there are approximately 55,000 independent trucking firms, i.e., firms that have their own customers and are not working under permanent lease as part of the fleet of a larger firm. About 35,000 of these firms are engaged in long-haul. They operate a total of 950,000 tractors with about 835,000 of those in long-distance service. For-hire revenue is estimated at $165 billion.

A.1 EXHIBITS

These numbers, together with a detailed distribution of TL and LTL companies across size and length-of-haul categories are displayed in Exhibits A-1 and A-2. You will see that the for-hire industry is broken into three broad categories: TL, LTL and Other, which comprises household goods and parcels.

The length-of-haul categories are based on the average length of haul of a company and are shown below:

Short-haul:		less than 150 miles
Long-haul:	short regional:	150 to 300 miles
	long regional:	300 to 700 miles
	long-haul:	more than 700 miles.

Exhibit A-3 provides a variety of financial and operating information on the larger companies, those included in the Transportation Technical Services (TTS) Blue Book of the Trucking Industry, which contains data on approximately 2,500 firms, the Class I and II carriers that are required to report financial data to DOT. These data account for virtually all of the firms in the LTL sector. As already noted, much TL activity is accounted for by smaller firms whose data is not included in the Blue Book. Exhibit A-4 shows the breakdown of operating costs for Blue Book companies across a number of categories.

Exhibit A-1
2000 VMT Estimates
(billions of VMT)

	Private	For-hire TL	For-hire LTL
Regional and long-haul	One-to-few long-haul Team: 8.0 Solo: 25.0 One-to-many regional 48.0	Long-haul Team: 7.7 Solo: 26.2 Long regional 29.5 Short regional 14.0	8.0
Local and short-haul	50.0	30.0	

Exhibit A-2
ICF Motor Carrier Population Estimates

Carrier Type	Tractor Size Class	Average Length of Haul	Companies	Percent	Tractors (1,000)	Estimated Revenue (1000,000)	Estimated VMT (1,000,000)
LTL	1-24	Under 150	431	70%	2	679	203
		150 to 300	71	12%	1	148	44
		300 to 700	78	13%	1	199	59
		Over 700	36	6%	0	82	26
		Total	616	100%	4	1,109	333
	25-99	Under 150	46	34%	2	347	103
		150 to 300	38	28%	2	381	114
		300 to 700	34	25%	2	341	102
		Over 700	18	13%	1	177	53
		Total	136	100%	7	1,245	372
	100-499	Under 150	5	10%	1	131	39
		150 to 300	17	33%	3	508	152
		300 to 700	21	41%	5	855	255
		Over 700	8	15%	2	239	71
		Total	52	100%	11	1,732	517
	500+	Under 150	1	4%	1	244	73
		150 to 300	5	14%	4	1,049	313
		300 to 700	18	50%	35	8,775	2,619
		Over 700	11	32%	53	13,153	4,189
		Total	35	100%	93	23,221	7,194
Total LTL			839		115	27,307	8,416
TL	1-5	Under 150	15613	39%	16	3,307	2,645
		150 to 300	4379	11%	7	1,010	808
		300 to 700	6954	17%	12	1,575	1,260
		Over 700	12878	32%	22	3,876	3,101
		Total	39824	100%	56	9,768	7,815
	6-24	Under 150	1398	20%	16	2,213	1,771
		150 to 300	1364	19%	18	2,505	2,004
		300 to 700	2496	35%	31	4,348	3,478
		Over 700	1897	27%	24	3,302	2,642
		Total	7154	100%	88	12,369	9,895
	25-99	Under 150	560	15%	26	3,642	2,914
		150 to 300	763	20%	36	5,124	4,099
		300 to 700	1459	38%	68	9,718	7,774
		Over 700	1061	28%	50	7,113	5,690
		Total	3843	100%	180	25,597	20,478
	100-499	Under 150	129	12%	23	2,989	2,391
		150 to 300	196	18%	38	4,961	3,969
		300 to 700	381	35%	78	10,323	8,259
		Over 700	369	34%	68	8,977	7,182
		Total	1076	100%	207	27,250	21,800
	500+	Under 150	12	7%	8	1,155	924
		150 to 300	31	18%	22	3,138	2,510
		300 to 700	51	28%	94	13,618	10,894
		Over 700	84	47%	118	17,147	13,718
		Total	178	100%	242	35,059	28,047
Total TL			52075		772	110,042	88,034
Total Other			1556		41	30,450	NA
Approximate Total			55 Thousand		950 Thousand	165 Billion	100 Billion

Exhibit A-3
TTS Blue Book Financial Data, by Carrier Type, Size Class, and Area of Operation

Operation Type	Size Class	Average Length of Haul	Companies	Operating Ratio	Percent of Companies with Operating Ratio < 1	Return on * Transportation Investment %	Long Term Debt to Equity Ratio	Percent of ** Companies with Debt to Equity Ratio < 1
LTL	1-24	Under 150	5	96.0	80	10	0.46	20
		150 to 300	5	95.5	100	17	0.66	80
		300 to 700	6	93.6	100	3	0.06	33
		Over 700	1	94.7	100	NA	1.00	NA
		Unspecified	28	97.0	82	5	0.64	36
		All	45	96.2	87	7	0.54	40
	25-99	Under 150	11	92.9	91	11	0.51	91
		150 to 300	9	97.0	100	16	0.72	67
		300 to 700	9	97.6	78	10	0.57	56
		Over 700	5	93.1	100	26	0.11	60
		Unspecified	NA	NA	NA	NA	NA	NA
		All	34	95.2	91	14	0.52	71
	100-499	Under 150	1	98.0	100	29	0.26	100
		150 to 300	4	90.3	100	21	0.23	50
		300 to 700	5	98.8	80	10	1.50	60
		Over 700	NA	NA	NA	NA	NA	NA
		Unspecified	1	NA	100	NA	NA	0
		All	11	91.4	91	16	0.94	55
	500+	Under 150	1	96.2	100	7	0.00	0
		150 to 300	2	88.4	100	29	0.29	50
		300 to 700	9	93.4	100	16	0.71	67
		Over 700	2	92.7	100	11	0.03	50
		Unspecified	NA	NA	NA	NA	NA	NA
		All	14	92.7	100	17	0.50	57
TL	1-24	Under 150	34	99.3	74	2	0.48	53
		150 to 300	30	98.2	67	8	0.44	52
		300 to 700	68	97.7	72	9	0.42	60
		Over 700	47	113.3	51	2	0.73	45
		Unspecified	122	95.9	78	4	0.29	27
		All	301	99.9	70	5	0.42	43
	25-99	Under 150	46	97.1	72	2	0.82	52
		150 to 300	49	96.8	65	5	0.76	43
		300 to 700	109	98.4	66	5	1.04	46
		Over 700	72	97.5	68	5	1.10	44
		Unspecified	22	100.9	59	5	0.52	64
		All	298	97.9	67	4	0.93	47
	100-499	Under 150	12	100.1	58	-2	0.95	42
		150 to 300	15	96.9	80	7	1.00	47
		300 to 700	22	98.2	77	3	1.03	41
		Over 700	24	96.0	88	7	1.88	42
		Unspecified	8	91.1	88	9	0.95	25
		All	81	96.9	79	5	1.26	41
	500+	Under 150	1	91.8	100	15	1.45	0
		150 to 300	2	99.2	50	0	0.00	50
		300 to 700	2	87.8	100	7	0.02	50
		Over 700	4	96.6	75	6	1.22	50
		Unspecified	NA	NA	NA	NA	NA	NA
		All	9	94.7	78	7	0.79	44

* Companies with leased tractors were removed from the analysis to obtain a well defined measure of return on transportation investment. Unless leases are capitalized,the use of leased equipment will cause an understatement of the value of the capital employed in the business.

** Companies with no equity and long term debt were counted as having a debt to equity ratio greater than 1.

Exhibit A-4
2000 TTS Blue Book Summary of Operating Costs by Carrier Type, Size Class, and Area of Operation

Operation Type	Size Class	Average Length of Haul	Companies	of Total Driver Salaries[1]	Other Labor[2]	Fuel	Maintenance	Insurance	Taxes[3]	Depreciation[4]	Equipment[5]	Misc[6]
LTL	C1:1-24	0-150	6	32	23	7	5	4	2	4	11	12
		150-300	6	34	14	11	6	4	3	4	14	10
		300-700	8	28	21	6	3	3	1	3	20	14
		Over 700	4	22	5	5	3	4	1	3	43	14
		Unspecified	20	28	20	6	4	3	2	4	22	11
		All	44	29	18	7	4	4	2	3	21	12
	C2:25-99	0-150	17	36	17	9	6	3	4	5	8	12
		150-300	12	33	22	7	3	3	3	2	14	13
		300-700	13	36	19	9	5	4	4	4	8	11
		Over 700	7	34	14	12	5	3	3	6	11	11
		Unspecified	8	32	12	13	6	3	3	6	11	13
		All	57	34	17	9	5	3	3	5	10	12
	C3:100-499	0-150	1	49	18	7	3	1	5	5	5	7
		150-300	9	37	23	6	4	2	3	5	8	11
		300-700	10	33	23	9	4	3	3	4	9	11
		Over 700	2	32	21	8	3	2	2	3	16	13
		All	22	35	23	8	4	2	3	4	9	11
	C4:500+	0-150	1	32	37	5	3	1	4	8	2	8
		150-300	4	45	18	3	4	3	3	3	6	14
		300-700	6	28	34	6	3	3	4	6	5	10
		Over 700	2	35	33	4	3	2	3	3	7	9
		All	13	35	29	5	3	3	3	5	6	11
TL	C1:1-24	0-150	25	31	13	8	8	4	4	5	17	11
		150-300	14	18	9	12	4	4	2	3	39	9
		300-700	32	25	13	14	6	3	3	4	21	11
		Over 700	35	27	8	13	4	4	3	6	21	14
		Unspecified	94	19	16	9	4	3	2	4	30	13
		All	200	24	12	11	5	4	2	4	25	12
	C2:25-99	0-150	56	34	10	11	8	4	4	8	12	9
		150-300	67	33	10	12	7	4	4	6	15	9
		300-700	151	33	9	16	6	4	4	8	11	9
		Over 700	110	27	7	18	6	4	3	8	18	9
		Unspecified	38	27	9	12	5	4	2	6	16	18
		All	422	31	9	15	6	4	4	7	14	10
	C3:100-499	0-150	15	30	14	10	6	3	4	7	17	10
		150-300	19	37	10	11	6	3	4	6	18	5
		300-700	50	31	8	13	6	4	3	7	20	9
		Over 700	28	30	9	16	5	4	4	9	15	9
		Unspecified	10	32	8	13	7	3	3	7	18	7
		All	122	32	9	13	6	3	3	7	18	8
	C4:500+	0-150	1	0	43	0	0	2	0	0	0	54
		150-300	5	46	8	8	6	4	3	6	7	11
		300-700	7	16	8	6	3	4	2	5	50	6
		Over 700	9	35	5	13	5	4	3	7	19	9
		Unspecified	2	32	1	4	5	1	4	4	42	6
		All	24	31	8	9	4	3	3	6	26	11
Household Goods Carrier	C1:1-24	0-150	2	3	15	0	2	1	1	2	10	66
		Unspecified	20	24	23	5	2	3	1	3	18	20
		All	22	22	22	4	2	3	1	3	17	25
	C2:25-99	150-300	1	19	22	2	1	2	1	8	41	3
		300-700	2	22	21	2	2	2	1	4	34	12
		Over 700	2	14	21	4	1	3	1	2	41	12
		Unspecified	7	30	27	5	4	6	2	4	10	11
		All	12	25	25	4	3	4	2	4	22	11
	C3:100-499	150-300	1	0	22	0	1	3	0	2	64	8
		300-700	1	0	26	2	3	5	0	1	58	5
		Over 700	1	24	13	3	2	3	0	2	5	47
		All	3	8	20	2	2	3	0	2	43	20
Parcel Delivery	C1:1-24	0-150	2	40	21	15	3	3	1	1	11	6
		Unspecified	4	54	19	4	3	2	2	2	3	12
		All	6	48	19	9	3	2	2	2	6	10
	C4:500+	Unspecified	1	35	37	2	2	1	1	3	4	15
		All	1	35	37	2	2	1	1	3	4	15

[1]Includes salaries, benefits and fringes of drivers and helpers. Fringes were distributed based on % of fringes to wages
[2]Includes salaries and fringes of cargo handlers and front office staff and commissions paid to HHG carrier agents.
[3]Includes operating taxes and licenses.
[4]Includes depreciation and amortization
[5]Includes equipment rents without driver, payables to HHG carriers and purchased transportation.
[6]Includes communications, utilities and other operating supplies and expenses.

(i) Estimates of Specific Data Points

This part contains our estimates and methods regarding: number of companies; number of tractors; revenue; number of truck drivers in long-haul service; and truck VMT.

(ii) Number of Companies

1) Data Sources

- Transportation Technical Services (TTS) National Motor Carrier Directory (NMCD) (2000) lists approximately 22,000 companies.
- ATA's North American Truck Fleet Directory (NATFD) (2000) has approximately 38,000 companies.
- Economic Census (1997) has 47,000 long-distance trucking establishments (sum of North American Industrial Classifications (NAICs) 48412, 4842102, and 48423) (does not include self-employed).
- FMCSA database (2001) says 300,000 for-hire firms (authorized plus exempt).
- University of Michigan Professor Francine Lafontaine says (1998) 320,000 owner-ops.

2) Analysis

These numbers are not in conflict with each other. Neither the NMCD nor the NATFD claims to be a universal listing and neither comes close to capturing all of the smallest companies, the independent owner-operators. Most owner-ops probably call themselves self-employed, so the Census number is a plausible estimate. In fact, the Census and the NATFD are close enough that they reinforce each other. Because listing in a private directory is a voluntary act on the part of a firm, no such listing is going to capture all small companies..

FMCSA shows 180,000 carriers with three power units or less. Given that plenty of owner-ops do not have their own DOT numbers, the FMCSA number does not contradict the Lafontaine number. Lafontaine's survey did not specifically define owner-ops but relied on self-characterization of firms in tax returns and similar documents. It is a reasonable surmise, however, that her number, 320,000, covers firms with one to five tractors. (This surmise is supported by John Siebert of the Owner-Operators Independent Drivers Association (OOIDA).) In the one-to-six range, FMCSA has about 260,000 companies (distributing unclassified companies over the size classes according to the distribution of the classified companies).

That leaves about 40,000 companies in the FMCSA census with seven or more power units. Some of these firms are local operations. In the TTS Blue Book, approximately 30 percent of the TL companies are local. A similar proportion, about 31 percent, may be derived from the Economic Census. Using this percentage, we may estimate that approximately 70 percent, or 28,000, of the FMCSA companies with seven or more power units are long-distance operations. The FMCSA number is not necessarily in conflict with the Census figure of 47,000 long-distance firms with employees; the Census total has to include a number of firms with fewer than seven power units. It must also include some independent owner-operators who employ a few drivers.

As noted above, a University of Michigan study found approximately 320,000 owner-ops. OOIDA estimates that perhaps 20 percent of these, approximately 64,000, are independent. That estimate is based on the fact that 20 percent of OOIDA's approximately 70,000 members have authority. If we assume this ratio holds across all owner-ops and we assume all owner-ops with authority are independents, then we find that 20 percent of owner-ops are unaffiliated independents. But neither assumption appears very strong.

It seems plausible that those operators who take the time and spend the money necessary to be OOIDA members will have a greater propensity to obtain authority than do other owner-ops. Further, it is simply not plausible that all operators with authority are independents. Authority is obtained with a one-time-only expenditure of $300, and there is no cost to keeping it, whether or not it is used. It is reasonable to suppose that there is a substantial number of owner-ops working under lease who have their own authority and do not use it. Application of the 20-percent assumption yielded an estimate of 64,000 independents; perhaps 40,000 is a more realistic number.

This estimate of the number of independent owner-ops can be combined with the TTS NMCD to develop an estimate of the total number of trucking companies. The NMCD is useful for this purpose, because it has number of trucks and tractors per company. It is a reasonable supposition that a company that takes the trouble to fill out the form for the NMCD is not an owner-op working under lease. Such an operation would have little incentive to list itself in a directory. Of the 22,000 firms in the NMCD, approximately 8,000 have one to five tractors. Given our estimate of 40,000 independent owner-ops, that means there are 32,000 such firms not in the NMCD. This leads us to a total estimate of something more than 50,000 independent firms, let us say 55,000 (as shown in Table 2). We noted above that around 30 percent, or a bit more, of TL firms have local operations. On this basis, we estimate that about 35,000 independent trucking firms are engaged in long-distance service (regional and long-haul) (Table 1).

(iii) Tractors

1) Data Sources

- Vehicle Inventory and Use Survey (VIUS) (1997) has 745,000 for-hire tractors.
- Economic Census (2000) has 940,000 for-hire tractors.
- NMCD (2000) says 930,000 for-hire tractors.
- NATFD (2000) says 1,100,000 for-hire tractors.
- FMCSA Census says (2002) 1,300,000 for-hire tractors.

2) Analysis

Given the somewhat rough character of all these data sources, the range of 745,000 to 1,300,000 is not a wide one, especially since the highest estimate is five years later than the lowest estimate. (Also, there is probably some double counting in the FMCSA number.) OOIDA estimates 1.4 tractors per owner-operator. Thus, our estimate of 40,000 independent owner-ops implies 56,000 tractors used by these firms. The 8,000 owner-ops in the NMCD operate 22,000 tractors. That leaves 34,000 tractors in addition to the NMCD count for a total of about 950,000 for-hire tractors in 2000. This is the basis for the estimates in Tables 1 and 2.

This estimate is consistent with the Economic Census number, which is, in effect, the updating of the 1997 VIUS number. Since the VIUS count is rooted in vehicle registrations, there seems less danger of double counting than there is in the NATFD and FMCSA estimates. In these latter cases there is some potential for vehicles owned by one entity and leased to another to appear twice and, perhaps, for the same entity to appear more than once. We are comfortable with a rounded-off estimate of 950,000 tractors in for-hire service.

(iv) Long-distance Revenue

1) *Sources*

- The Economic Census
- TTS The Motor Carrier Industry in Transition
- NMCD
- Number of tractors in service.

2) *Analysis*

- The Census has 1997 revenue estimates for the following NAIC categories:
    - general freight, long distance (TL and LTL) (48412)
    - household goods (HHG), long distance (4842102)
    - specialized freight, long distance (48423).

The Census has long-distance revenue for 1997 for establishments (firms with payrolls) only and for 2000 for firms with and without employees. However, the 2000 number for specialized freight is only for 4842, i.e., with local included. Therefore, we took the ratio (1.24) of category 4842 in 2000 to 4842 in 1997 and applied that to the 1997 sum of categories 4842102 and 48423 to get 2000 estimates for these categories. This gives us $147 billion for all three categories. It seems, however, that this does not include surface UPS. The LTL long-distance general freight in 1997 is $25 billion; with surface revenue of $22 billion, UPS be included in this number. And UPS is not in the specialized freight. We add UPS to the Census and the result is $169 billion.[1]

In "The Motor Carrier Industry in Transition,"' TTS estimates 1999 revenue of interstate for-hire of $145 billion (including packages) plus $11 billion for exempt trucking: so, $156 billion for 1999. Now, Census gives growth rates from 1999 to 2000 for general freight long distance,

[1] While we call this long-haul revenue, we have to note that it includes local pick-up and delivery for LTL and package services and some strictly local package moves. We have no convenient method for separating these elements.

HHG, and specialized freight long-distance (firms with payrolls). This gives a weighted composite growth rate of 0.061; 156 x 1.061 = $166 billion.

ICF developed a TL estimate combining the NMCD TL revenue estimate with our own estimate of the number of tractors in TL, for-hire service. For LTL, household, goods, and packages, we can use the Blue Book data without further adjustment; virtually all of the activity in these areas is accounted for by firms large enough to file financial reports with DOT. The issue is with the TL sector and its tens of thousands of small companies. We approach this by supplementing the NMCD estimate with an estimate based on number of tractors used by owner-ops. We estimated that there are 40,000 companies with five or fewer tractors, and 8,000 of these firms are listed in the NMCD included in its revenue estimate. For the remaining 32,000 owner-ops we used the previously cited values of 1.4 tractors per owner-op and revenue of $125,000 per tractor. Added to the NMCD revenue number, this yields an estimate of $110 billion for all TL revenue. If we add LTL, packages, and HHG to this, we get $167 billion. The only part of this we can explicitly identify as short-haul is about $14 billion from the TL portion.

Thus, our estimates for long-haul revenue are:

- Census + UPS = $169 billion.
- TTS = $166 billion.
- ICF = $153 billion.

Given the rough nature of the data, these estimates are fairly close to each other. They not only reinforce one another but also support the other estimates of number of tractors and number of firms. We add back the short-haul TL of $14 billion and we have a total estimate of $167 billion or $165 billion in round numbers.

(v) Number of Truck Drivers in Long-haul Service

1) Sources

- ICF estimate of number of tractors
- TTS Blue Book
- TTS MCIT

The number of truck drivers was estimated on the basis of number of tractors. We are focusing on effects on TL, for-hire long-haul drivers and private long-haul drivers. For that reason, we we did not estimate number of long-haul drivers in LTL and package operations. The treatment of long-haul LTL and package drivers is discussed in Chapter 5.

The ICF estimate of number of tractors in for-hire service in 2000 is 950,000.

From that, we subtract the following:

- LTL 115,000 (TTS Blue Book)

- TL local 125,000 (ICF estimate in Table 3-1)
- HHG local 10,000 (TTS Blue Book)
- Package 12,400 (TTS Blue Book)

262,400

950,000 – 262,400 = 666,600 or, approximately, 670,000 tractors in TL long-haul service.

Analysis of Blue-book data shows a TL driver/tractor ratio of approximately 1.0. Therefore, there are about 670,000 TL drivers in long-haul service.

In TTS MCIT (p. 63), number of private tractors in 1997 is estimated (on the basis of 1997 VIUS) at about 748,000, slightly less than an estimated 752,000 for-hire tractors. Both numbers can be rounded to 750,000 without loss of accuracy. Our estimate of 950,000 for-hire tractors in 2000 yields an estimate of about 810,000 for-hire tractors in long-haul service. (950,000-125,000 (TL local)-10,000 (HHG local)-2,500 (package local)=812,500) We can assume that the 1997 parity between numbers of for-hire and private tractors continues, but we cannot assume that the number of private tractors in long-haul service is equal to the number of for-hire tractors in long-haul service. A larger fraction of private tractors will be in local and short-haul service than is the case for TL tractors. In long-haul operation (regional and long haul), VMT for private carriage and for-hire carriage is roughly equal. In local operation, private VMT exceeds for-hire VMT by roughly two-thirds (see VMT note). There are no data to allow a precise division of private tractors between long-haul and local service. We think it is reasonable to assume that the number of private tractors in long-haul service is about 700,000, slightly less than the for-hire number of 810,000.

Based on interviews and our team's knowledge of the industry, we believe that the driver/tractor ratio in private long-haul and regional service is approximately 1.0. Like TL firms, private carriers tend to provide each driver with a tractor dedicated to his use. Therefore, there are approximately 700,000 long-haul private drivers.

810,000 + 700,000 = 1,510,000 drivers in long-haul service or, approximately, 1,500,000. Of these, 670,000 are TL drivers and 700,000 are private. The balance are LTL and package. From other sources, we have firm estimates of a total of 3.1 million truck drivers, so this estimate is consistent with 1.5 million short-haul drivers.

(vi) Estimate of Truck VMT

Our estimates of truck vehicle miles of travel are shown in Exhibit 3-B. These estimates were developed on the basis of trucking revenues or, for private carriage, costs. If one knows revenue and revenue per mile, one can derive miles of truck travel. Revenue ÷ revenue per mile = truck miles of travel. The same relationship, obviously, holds for costs. The estimate of LTL regional and long-haul VMT is from the TTS Blue Book. It is included here simply for the sake of completeness, as, for reasons discussed in Chapter 5, we found that none of the options would significantly increase the cost of LTL line-haul operations. The details of developing the TL and private estimates are given below.

1) <u>*Sources*</u>

- TTS MCIT
- TTS America's Private Carriers (APC)
- ICF estimate of TL revenue
- 2000 Economic Census
- 1997 Commodity Flow Survey

2) <u>*Analysis*</u>

- Private Carriage

(vii) Long-haul

Estimates of imputed revenue for private carriage in 1999 are provided on page 29 of the TTS Motor Carrier Industry in Transition. TTS imputed revenues for private carriage are, in fact, cost estimates. The total cost for private long-haul movement is put at $114.5 billion. Another TTS publication, America's Private Carriers (APC), offers an estimate (p. 99) of $1.46 per mile for private tractor fleets. Since the great preponderance of regional and long-haul moves will use tractor-trailers, this number was chosen for the VMT estimate. Brought up to 1999 dollars (from 1993) , it is $1.52. 114.5 billion ÷ 1.52 = 75.4 billion. To bring the estimate to 2000, a growth factor from the 2000 Economic Census (Table 2.1) was used: 7.6 percent from 1999 to 2000 for revenue from long-distance, general-freight trucking. 75.4 x 1.076 = 81.1 billion VMT of regional and long-haul private carriage.

This amount was distributed over the two private-carriage scenarios in the following manner. It was assumed that the regional scenario of a single facility shipping to many points within a 500-mile radius accounts for 60 percent of private, non-local VMT. This assumption is somewhat arbitrary, but not unreasonable. We may take ton-miles as a rough proxy for VMT. The 1997 Commodity Flow Survey (CFS) (p. 11) shows that, for moves over 100 miles, 60.0 percent of private ton-miles is for moves under 500 miles. 0.6 x 81 = 48.6, and we round down to 48.0.

Eight billion VMT are assumed to be in team operations. We assume ten percent of regional/long-haul private moves are team (and make the same assumption for TL operations). We believe the use of teams for moves under 1,000 miles is rare. We assume that the percentage of ton-miles may be taken as the percentage of vehicle miles. The 1997 CFS (p. 11) indicates that about 30.0 percent of for-hire ton-miles are in moves of over 1,000 miles. The same fraction for private carriage is 11.0 percent. We assume that private carriers will tend to use teams when justified by distance, especially in light of the concern of many of them for bringing their equipment home relatively quickly. Regarding TL for-hire, we note that many long moves are made by solo drivers, especially in cases where drivers are willing to stay out for long periods. This behavior is thought to be characteristic of a non-trivial number of owner-operators, for example. It is also the case that LTL firms would account for a disproportionate share of the moves over 1,000 miles; the four national LTL companies have average lengths of haul around 1,200 miles. Accordingly, we chose the figure of 10 percent for TL team use.

(viii) Short-haul

TTS MCIT (p. 29) gives private local cost as $114.9 billion. In order to find a cost per mile for local moves, we turned again to TTS America's Private Carriers. Local movements will be dominated by straight trucks. Cost per mile for private straight trucks is given as $2.11 (p. 105). But some local moves will be in tractor-trailers. According to TTS MCIT, there are almost ten times as many straight trucks as tractor trailers with operating ranges of less than 100 miles. But it is reasonable to assume that the tractor trailers will have longer average hauls and, thus, a fraction of VMT considerably higher than the number of units would suggest. Accordingly, we assume, somewhat arbitrarily, 75 percent of local/short-haul VMT as straight truck, 25 percent as tractor trailer. On this basis, the composite cost per mile is $1.95. This is equivalent to $2.54 in 1999. 114.9 billion ÷ 2.54 = 45.2 billion VMT in 1999. The growth factor from the Economic Census (Table 2.1) is 1.065 for local general freight trucking. 45.2 x 1.065 = 48.2, and we round to 50 billion VMT for private local carriage in 2000.

(ix) For-hire

1) TL Long-haul

VMT for regional and long-haul TL operations was arrived at using ICF's TL revenue estimates (in the Industry Profile) and a figure of $1.25 for revenue per tractor-mile (based on industry interviews and the views of the experts on the team). The revenue estimate for 2000 for TL firms whose average haul exceeds 150 miles is $96.7 billion. 96.7 billion ÷ 1.25 = 77.4 billion VMT. These VMT are distributed over long-haul, long-regional, and short-regional companies as shown in the table. This distribution follows the distribution of revenue as shown in Table XX-1.

2) All for-hire Short-haul

We did not attempt to separate TL and LTL local/short-haul revenues and VMT for this purpose. TTS MCIT (p. 29) gives for-hire local and intrastate revenue in 1996 as $71.1. As with private short-haul, we use a figure (1999 prices) of $2.54 per mile. Using a growth factor from the 2000 Economic Census for local general freight of 6.5 percent, we obtain 29.9 billion VMT. 1.065 x (71.1 billion ÷ 2.54) = 29.9 billion. We round to 30 billion.

APPENDIX B.
SUMMARY OF SURVEYS AND RELATED DATA SOURCES FOR BENEFITS CALCULATIONS

B.1 OVERVIEW

ICF Consulting's preliminary research began with a thorough review of the documents referenced in both the November 1999 Annotated Literature Review on HOS and the April 2000 NPRM RIA. Research staff also acquired and reviewed additional background materials that had been submitted to DOT Docket No. FMCSA-97-2350.[2] The initial goal was to develop an understanding of the factors that are believed by current experts to contribute to fatigue and/or to fatigue-related crashes among commercial truck drivers. We also worked to identify any methodological challenges problems particular to this area of study.

Our review of the literature led us to develop an operating framework whereby drivers' working schedules are linked to the amount and quality of their sleep, which is closely related to their level of alertness, which in turn affects driver safety. Our next step was to examine more closely the working, driving, and sleeping habits of truck drivers to determine what patterns exist, how they are interrelated, and, if possible, to quantify the relationships. We therefore identified and acquired the best sources of data and information available that would allow us to analyze patterns of sleeping, driving, non-driving work, breaks, naps, and time off-duty for broadly representative samples of truck drivers.

We were also interested in data sources that would allow us to separate out the employee, industry and truck characteristics which recent literature and our own analysis of industry operations had indicated would likely impact sleep/work patterns. For example, data and information from several industry contacts indicated that short haul drivers would most likely be minimally affected by proposed daily work limits, and that a small but significant percentage may be affected by proposed weekly work limits.[3] In addition, we expected that OTR drivers who are permanent employees of a company would have a more regular schedule than owner-operators performing similar work. Of the subset of employees, we expected that employees of private carriers would have shorter working hours and more regular schedules than employees of for-hire firms. We expected a similar disparity between unionized employees and non-union employees. The literature also indicated that team drivers are likely to work more regular hours and get more sleep than solo drivers. With these many points of potential differentiation, it was important that our data sets allow us to distinguish between groups characterized by the type of driver, type of firm, and the physical range of operations.[4] We analyzed these groups separately to identify and, if necessary, account for differences in the patterns of sleep and work.

[2] Documents were deemed relevant if they addressed topics such as driver fatigue, truck accidents, truck safety, road safety, trucking operations, sleep physiology, or other areas of importance to the regulatory analysis. Research staff searched the docket for these and other key terms, as well as for the names of authors and institutions that have been involved in relevant research.

[3] See Appendix K for a list of contacts.

[4] Potentially dissimilar driver types included: owner-operators and employees, union and non-union drivers, teams and non-teams, and drivers with varying levels of experience. Potentially dissimilar firm types included: for-

We were also able to use our data sources to help address other, related issues in our analysis. For example, we used information on work and driving schedules to estimate the number of new drivers that will be needed to meet current operational demands under the proposed regulations. We were also able to use data on crashes and truck drivers' years of driving experience to evaluate the relative crash propensity of new drivers.[5] One study had detailed information on the time drivers spend waiting to load and unload, which helped inform our understanding of the composition of a driver's work day, and apply that understanding to the schedule modeling process.

The summaries below describe the major sources of data used in our analysis of working and sleeping patterns, as well as other purposes. Each summary provides a general description of the data set, its overall strengths and weaknesses, and any qualifications applicable to its use. It explains any modifications to the data that we found necessary to perform, including the division of the data into selected subsets. The summary next describes how we used the information contained in the data, noting the variables of interest and any special treatment each required. Following the summaries we provide a comparative discussion of the results from the various data sets, and offer explanations for apparent discrepancies.

(i) University of Michigan Trucking Industry Program (UMTIP) Driver Surveys (1997-1999), by Dale Belman et al.*, with the University of Michigan Institute for Social Research*

1) Basic information

The first wave of the UMTIP data collection effort resulted in 573 long surveys completed by truck drivers at 19 midwestern truck stops between July and October of 1997. The second phase of the driver survey, conducted between summer 1998 and spring 1999, used the same methodology and essentially the same questions at 12 truck stops and increased the sample size to over 1,019 valid observations. Truck stops were chosen based on the number of overnight parking spaces available, which gives a measure of traffic volume. The probability sampling technique employed ensures that the selected truck stops match the distribution of overnight parking spaces by both state and size category. A potential respondent was interviewed if he or she reported being a truck driver, possessed a Commercial Drivers License (CDL) and was driving a tractor trailer at the time of the interview.

2) Representativeness and strengths

The UMTIP driver survey provides a representative picture of certain segments of the regional and long-haul OTR truck driver population. The survey team did not intend to capture every aspect of the trucking industry; rather, it was the express intent of the authors to sample regional and long-haul OTR truck drivers. For example, the authors clearly state that local pickup and delivery drivers are underrepresented. Our analysis of their data further indicates that those short-haul drivers are not a representative sub-sample of the short-haul population. The survey design addressed the potential for bias by applying randomization techniques to the choice of

hire and private carriage, TL and LTL. Ranges of operation included local, regional, short-haul and long-haul operations.

[5] See section 8.7.

truck stops, the choice of potential respondents, the day of the week, and the time of day. We took care to separately analyze subsets of the driver population, to the extent possible, to ensure that dissimilar subsets were not grouped together. The great advantages of the UMTIP driver survey are that it captures the portion of the driving population that will be most affected by the proposed regulations, it offers a rich range of information about its subjects, and its limitations are transparent.

3) *Variables*

The variables of interest contained in the UMTIP data set included hours spent sleeping, working and driving in the 24 hours leading up to the interview, hours worked in the last pay period,[6] and detailed variables concerning the timing and/or duration of activities during the last completed trip (e.g., waiting for a dispatch, loading/unloading, driving, etc.). After examining the language in the survey instrument, we concluded that the potentially ambiguous terms 'sleeping' and 'working' were sufficiently clarified to allow comparisons with other survey results.[7] For descriptive statistics and cross-tabs, we used sample weights to account for sampling bias due to the size of the truck stops selected as survey locations.[8]

In cooperation with the authors of the UMTIP driver survey, we studied customized statistical outputs for particular subsets of the population surveyed. These subsets were designed to match, as closely as possible and where appropriate, the industry segments determined by ICF Consulting to reflect the most relevant profile for the present regulatory impact analysis. In particular, this data set provided several useful variables on driver type (owner-operator, employee, union, non-union, teams), industry segment (for-hire, private carriage, truckload and less-than-truckload), range of operations (local, regional, long-haul) and size of firm, which enabled comparative analyses of many different sub-groups of drivers. For comparison with other data sets, we also found it useful to study miles driven in the past year and miles driven on a "typical run."

4) *Applications of data*

Initially we used results from the UMTIP driver survey to establish patterns of work and sleep for various subsets of the driver population, and to develop a more complete picture of how a typical week as a truck driver is structured. Second, we used the data to quantify the relationship between work and sleep, which we hoped to compare with similar relationships derived from other data sets. Third, we examined information on crashes and years of experience to establish the extent to which drivers new to the occupation may pose an increased safety risk. As we moved into the modeling phase of the analysis, we used UMTIP results to calibrate the RoutePro

[6] Drivers' responses pertaining to pay period were standardized to 7 days.

[7] The term 'sleep' as used in the survey meant all sleep in the last 24 hours, which, we concluded, would include naps. The term 'working' as used throughout ICF's analysis means all activities conducted while on-duty, including driving and non-driving work. Non-driving work was clarified in the UMTIP survey as follows: time spent on-duty working but not driving, including time spent on loading, unloading and drop and hook, time spent waiting for things such as loading and unloading, getting into a dock, for dispatches or for bills to be cut, but not counting meals or sleep time.

[8] See Let it Be Palletized, Appendix C, for a detailed explanation of how these weights were constructed and used.

scheduling software to ensure that it produced a realistic picture of the work schedules experienced by drivers in various segments of the trucking industry.[9] In addition, we used UMTIP data on sleep habits to check the plausibility of the subsequently developed sleep schedules for various driver types.

An analysis of for-hire team drivers was conducted separately to study the driving and sleeping patterns particular to that group, in accordance with the ICF trucking industry profile. Trainer/trainee teams were excluded completely because they comprise a very small portion of the driving population, their driving patterns may be significantly different from those of the general driving population, and they are not likely to be affected by the proposed regulatory changes. Our analysis of possible differences between drivers of refrigerated units and those of box vans showed no significant differences between these groups. However, only for-hire drivers were asked to identify the type of truck they were driving on the day of the interview, so this analysis was necessarily incomplete.

We examined TL and LTL operations for a smaller sub-sample of the for-hire workers. (Not all drivers were asked the question that generated the TL/LTL variable). The sub-sample that responded to the TL/LTL question showed slightly different characteristics than the general sample. This led us to conclude that the sample that responded to this question is not representative of the general sample of for-hire drivers. Moreover, the sample means of the two groups did not show statistically significant differences in the expected direction. For our spreadsheet modeling work, we therefore used the pooled summary statistics for the combined sample of OTR drivers, rather than separating TL and LTL drivers within the for-hire segment.

5) Survey-specific issues and their resolution

A significant percentage (13%) of drivers in the UMTIP survey reported a combination of sleep, driving and non-driving work time that equaled more than 24 hours in a day. We attribute this result to several features of the survey. First, the duration of various activities was investigated through nine questions in wave 1 of the survey and ten questions in wave 2, and the duration of each activity is subject to measurement error. Second, the questions were spread throughout the survey, which prevented easy detection of unlikely totals. Third, the survey had no internal control to prevent totals greater than 24 hours. Fourth, despite careful wording of the questions (usually: "in the last 24 hours"), some respondents may have reported the full duration of an activity that actually began more than 24 hours ago.

To address the problem, we considered three methods of handling the observations that reported more than 24 hours of activities: 1) Drop them from the data set. This will produce an underestimate of the time spent on various activities because observations with detectable measurement error for work activities are more likely to be those on the high end of the distribution. In other words, measurement error is likely to be greatest (leading to observations dropped) for those who tend to work a greater number of hours. 2) Normalize the sum of work time and sleep time to 24 hours. This approach will overestimate, on average, the time spent on the day's activities because a driver's work day consists of more than work and sleep. That is, this approach does not account for time spent eating, showering, and other life activities on that given day. 3) Normalize the summed duration of all activities to the average amount of time

[9] See Appendix C, Section 2.

spent by an OTR driver on work and sleep in a 24-hour period. The average here is calculated from the values reported by all OTR drivers with no apparent measurement error, i.e. those whose reported activities have a total duration of less than 24 hours. This method may underestimate the time spent on work-related activities because the drivers reporting a total of more than 24 hours of activities may represent a sample of drivers who typically do work (and sleep) more hours than the average driver.

The first and third approaches were favored because the second approach led to summary statistics well above what we had found in other surveys and in discussions with industry representatives. Many mean values for summary statistics did not differ in statistical significance between the first and third approaches. For instance, the number of hours driving for all OTR operators was calculated as 8.61 when dropping the observations (approach 1) and 8.65 when normalizing them to the average working plus sleeping time (approach 3). The primary use for these statistics was to help model patterns under current compliance levels in the spreadsheet modeling process. The current compliance baseline result from the spreadsheet was re-calibrated to be consistent with actual incremental crash incidence by industry sector. Because the values chosen would not alter relative differences among HOS proposals, for time spent on activities in the last 24 hours we use only the observations with 24 or fewer total hours reported. Statistics for other variables that did not concern hours per day were not affected by this decision.

A similar issue was raised with the variable 'hours worked per week', for which some survey subjects provided unlikely responses. Because no remedy is available to consider normalizing these observations, we dropped four observations where reported activities totaled to more than 126 hours of work per week (18 hours/day on average for 7 days).

We concluded that the data on local drivers was likely not representative of the local driver population because the survey was administered at truck stops, which are more likely to be patronized by long-haul drivers. According to Massie et al. (1997), local operations (routes of less than 50 miles from base) account for 58% of the large trucks in the United States and 28% of miles traveled. The UMTIP survey was administered to 103 short-haul drivers (10% of respondents). Although the responses were subsequently weighted to increase the representation of local drivers in the sample, we concluded that the local drivers sampled at truck stops were themselves likely not representative of local drivers as a whole. There are several reasons for this: local drivers do not drive as many miles on highways as long-haul or regional drivers, spend much of their work day on non-driving activities, have regular schedules that allow them to sleep and shower at home, may use vehicles refilled at company facilities, and may be discouraged from using truck stops as a matter of company policy. We therefore used data only on those drivers who classified themselves at the outset as primarily over-the-road (OTR), not "local pickup and delivery." We then divided the OTR analysis between long-haul and regional (as defined by >500 and ≤500 miles per average dispatch, respectively).

A potential methodological weakness of the UMTIP survey is that data was gathered only at Midwestern truck stops. Because it is unclear how this is likely to affect the sample, we do not make adjustments for this factor. A second weakness in the data is the incompleteness of the variable that allows for differentiation between TL and LTL drivers. As discussed above, we used the pooled summary statistics for the combined sample of OTR drivers, rather than separating TL and LTL drivers within the for-hire segment.

(ii) "Commercial Motor Vehicle Driver Fatigue, Alertness, and Countermeasures Study" (DFACS), 1997, by C. Abrams, T. Schultz, and C. D. Wylie

1) Basic information

Interviews were conducted in 1995 at high-volume, 24-hour truck inspection stations in four geographically dispersed states. The stations chosen provided geographic variety and a high density of long-haul drivers. The sample of drivers is composed of 511 long-haul drivers who were driving a loaded tractor-trailer, had driven at least 60,000 miles in the previous year, had been on the road at least 24 hours prior to the interview, and who had stopped at an inspection station. Drivers of straight trucks were excluded in order to focus the study on truck drivers involved in non-local operations.[10] The survey was designed to take less than 15 minutes to avoid possible bias due to refusals.

2) Representativeness and strengths

The main strength of the DFACS survey is its focus on the subset of the driving population that is most likely to be affected by the proposed regulations. This focus allowed for analysis with only minor modifications to or reductions of the dataset. In addition, the survey methodology was designed to parallel that of Beilock (1989)[11] and Braver et al. (1992), thus providing a quality check on the sample characteristics that increases our confidence in the validity of the data. Despite providing a much smaller number of observations than is contained in either Braver or Beilock, the demographics and job characteristics of the DFACS sample are very similar to those of both studies. We conclude that this survey represents the same population that is addressed in Braver and Beilock, namely long-haul over-the-road commercial truck drivers.

3) Variables

The DFACS data was most useful for its information on sleeping habits, which included temporal information not featured in most other data sources. The variables related to sleep were: start time and duration of the last main sleep period, the sleep period the time before last, and the next expected main sleep period. For each of the three days addressed in the questions, drivers were also asked for the location of sleep, whether sleeper berth time is split into two periods, and how much time is spent in the sleeper berth at one time. DFACS also provided other useful schedule-related variables: duration of the gap between waking and driving, duration of driving before taking a break, length of a typical break, and whether the driver takes naps during breaks. Four variables gave useful information on driver characteristics: whether the driver is an owner-operator, whether he is a union member, how frequently he drives as part of a team, and miles driven in the last year.

[10] Straight trucks used primarily for local operations. See, for example, Braver et al (1992).

[11] Beilock, R. (1989). 1988 RCCC Motor Carrier Safety Survey. Alexandria, VA: Regular Common Carrier Conference.

4) Applications of data

We used the DFACS dataset primarily to analyze the sleeping and napping habits and on-duty breaks of long-haul drivers. The detailed questions about sleep and breaks allowed us to analyze not only the amount of rest obtained but also the temporal relationship between rest periods of varying duration and quality. For example, we were able to establish a correlation between the time of day sleep began with the duration of sleep, which we could then compare to similar information from the Walter-Reed data set. While the DFACS survey's questions about work were not useful to our analysis of time spent on work and non-work tasks, we were able to use them to further develop our understanding of the temporal relationship between work and sleep periods. For example, it was useful to know how long after waking a driver began to drive,[12] and how many hours a driver preferred to drive before taking a break. These variables, in combination with those first described, helped us develop a more complete picture of how drivers' work days are structured. In some cases we were able to use information unique to DFACS to provide insight into the results from other data sets. Other useful variables in DFACS allowed us to analyze subgroups of drivers based on range of operations, driver type, and years of experience. We used the number of miles driven in the past year to compare regional and long-haul drivers, and we separately analyzed owner-operators and company employees, union and non-union drivers, and solo and team drivers. We used the years of experience variable to compare the distribution of experience across data sets.

5) Survey-specific issues and their resolution

A potential weakness in the DFACS study is that its sleep data is based on self-reporting, which we would expect to produce upward bias for variables addressing sensitive issues such as duration of sleep and rest. As a result, we consider its results to be comparable only to the self-reported measures of sleep in other surveys. A second potential weakness of the DFACS study is the authors' choice of interview locations. On one hand, because the truck drivers in the population targeted in this study are required to stop at open inspection stations, the choice of 24-hour, high-volume stations helped ensure a sample that is representative of a wide spectrum of truck drivers. On the other hand, inspection stations are operated by law enforcement agencies; despite the interviewers' efforts to clearly distinguish themselves from law enforcers, we would expect some amount of bias in the responses, particularly in the responses to sensitive questions. However, when we compared the DFACS responses to self-reported responses in other surveys, we found that the DFACS drivers reported similar amounts of sleep and napping, and comparable differences in behavior between various types of drivers (union and non-union, company employees and owner-operators, teams and solos).

In general, because the authors focused on a particular segment of the driver population, we were careful not to extrapolate results inappropriately to other subsets of drivers. For example, it would have been clearly inappropriate to draw conclusions about local drivers based on this study, because two of the prerequisites for participation make it unlikely that local drivers were represented. We were also careful about drawing comparisons between these results and those generated from wrist actigraph readings of actual sleep.

[12] Two variables addressed this relationship: the first referred to the last main sleep period and the second referred to the first day back on the job after two or more days off-duty.

(iii) Truck Stop Study and Truck Company Study Surveys, 1999, developed for "Motor Carrier Scheduling Practices and Their Influence on Driver Fatigue," (forthcoming), by Michael Crum, Paula Morrow and Carmen Daecher

1) Basic information

The data was developed from a short survey and a long survey that featured similar questions. The short survey (for the "Truck Stop Study"), was administered at five large truck stops located near major intersections of interstate highways in four geographically dispersed states. The truck stops were selected in part to ensure diversity of clientele, commodity type and product group. Based on traffic flow and personal judgment, survey staff determined both the frequency with which to approach potential subjects and the duration of data collection activities at a given truck stop. Data collection occurred during all periods of the 24-hour day between October and December 1999 and generated 502 usable observations.

The second, longer survey (for the "Truck Company Study") was distributed to top management, safety directors and dispatchers within each firm that agreed to participate. Truck companies were drawn equally from three stratified safety performance groups that comprised a universe of 21,292 firms. All firms were registered with the FMCSA as interstate motor carriers, employed at least four truck drivers, and had readily available safety information. The safety director of each firm was instructed to select three "typical" drivers to complete the survey. The drivers returned the survey in a sealed envelope to the safety director, who in turn sent it to the researchers. ICF analyzed only the 279 responses from truck drivers.

2) Representativeness and strengths

The surveys were designed to represent the universe of OTR truck drivers. While the drivers represented in the two surveys differed in their composition somewhat, we combined the two sets of data because our analyses were to be separate for distinct driver groups drawn from both sources. For example, the short survey was dominated by for-hire drivers (86%) while the long survey was split fairly evenly between for-hire and private fleet drivers (48% and 52%, respectively). The short survey also captured a larger share of owner-operators (34%) compared to company drivers than was shown in the long survey (12%). Because the composition of the short survey sample is comparable to that of other surveys and to our own industry analysis, we conclude that these discrepancies likely reflect selection bias in the long survey.

Interestingly, however, the drivers' responses to quantitative questions on the long survey do not reflect the biases we might expect based on its composition and selection methodology. We expected, for example, that the long survey might show a larger average amount of sleep and other rest across respondents because of the higher proportion of company drivers and because of possible measurement bias. In fact, we found only a small difference in sleep quantity was it not in the expected direction (8.0 hours of sleep on average for short form respondents compared to 7.6 hours for long form respondents). Drivers responding to the long survey also reported driving fewer miles, taking fewer naps and napping for shorter periods of time (all on average). An analysis of the long survey sample yielded a possible explanation for this result: several features indicate that the drivers responding to the long survey tended to be regional or short-haul drivers, not long-haul drivers. In particular, the short survey is dominated by drivers covering >500 miles per run (90%) and has average of 2 stops for pickup/dropoff per day while the long survey has a majority covering <500 miles per run (60%) with 5 stops for pickup/dropoff per day. These differences do not affect the quality of our results because we were careful to separate the analyses based on driver type and range of operations.

3) Variables

Several variables contained in the combined data set were of primary interest for our purposes. These included the amount of sleep obtained, the average number and duration of naps, and the typical number and duration of breaks taken (all pertaining to a typical workday). In addition, the data set provided several variables that allowed us to characterize the data and split it into appropriate subgroups for separate analyses. These variables differentiated between employees and owner-operators, employees of for-hire firms and those of private carriers, union and nonunion drivers, drivers who cover various ranges of operations, and drivers who work in team configurations.[13] To help filter out drivers that were not part of our analysis, we also used the average weekly mileage, distance of the average run and the number of stops made per day for pickups and deliveries. Although the surveys contained questions pertaining to driving habits and the amount of time spent on various non-driving work activities, the wording of the questions was not designed to capture discrete numbers and made those variables difficult to interpret for our purposes. Specifically, the survey did not contain a question that directly asked about the number of hours driven or worked in a day. We were unable to accurately estimate the number of hours driven in a day based on the number of miles driven in a week because the relationship between these two variables is non-linear. Thus our result was vastly unlike those produced from other surveys that contained more direct questions about driving and working habits.

4) Applications of data

We used the Crum data set to analyze the number and duration of naps and breaks, to supplement our analysis of sleep quantity for the relevant industry segments and driver types, and to infer time spent driving per day.

5) Survey-specific issues and their resolution

As discussed above, the short survey was administered directly to drivers at truck stops while the long survey was completed by drivers who had been selected by their company's safety director. Although these data sets represent different selection methodologies, we found that the composition of the two groups did not differ significantly along several dimensions. We therefore combine the two samples in our analysis.

[13] We removed from the analysis those drivers who reported that they "always", "frequently" or "sometimes" drive as a team.

(iv) "Study of Fatigue-Related Driving Among Long-Distance Truck Drivers in New York State, Volume 1: Survey of Long-Distance Truck Drivers," 1997 (revised 1998), by Anne T. McCartt, Mark Hammer, and Sandra Fuller (Institute for Traffic Safety Management and Research)

1) Basic information

Interviews were conducted in the spring of 1997 with a sample of 593 drivers at private rest areas (39%), public rest areas (32%) and roadside commercial vehicle safety inspection sites (28%) in upstate New York. Participating drivers had driven a tractor-trailer for at least six months, made overnight trips, and drove at least 50,000 miles per year. The objective of the survey was to help researchers better understand the driver, job and other factors associated with drowsy driving among long-distance commercial truck drivers. The dataset provides detailed information about the characteristics and working and sleeping habits of the population of truck drivers who will be impacted by the proposed HOS rules.

2) Representativeness and strengths

The survey captures a representative sample of long-haul over-the-road commercial truck drivers. A large majority reported having driven more than 85,000 miles in the past year, while a significant majority said they had driven more than 100,000 miles in the same period. The sample contained distributions of age and years of experience that mirrored the findings from other major studies. The composition of driver types was approximately evenly distributed between private fleet employees (38%), for-hire employees (35%), and owner-operators (27%), which is roughly comparable to that found in UMTIP and IIHS. One differentiating feature of this data set is the geographic origin of the drivers in the survey sample. A disproportionate number were licensed in New York (22%) while a similar number were licensed in other northeastern states (21%) and the majority were licensed in other states (61.2%) and a significant number were from Canada (16.5%).

3) Variables

There were several variables in this survey that related to sleep, napping, and the ways that truck drivers spread their sleeping time over the course of a day. The variables of greatest interest were: hours of sleep while off-duty, hours of longest sleep period while on the road, time of day of main sleep period (e.g. day, night, split, varies), and frequency of naps, and whether the required 8 hours off-duty is usually split into two periods. Two variables addressed time spent working and driving in a typical week. The survey also included three variables that enabled us to examine different groups of drivers: type of carrier (private fleet, for-hire, owner-operator, lease operator), union membership and miles driven for work per year. Finally, the variables on years of experience and crashes provided information on the crash propensity of new drivers.

4) Applications of data

The New York state study was used at the outset to learn about drivers' habits of sleeping, working and driving. The two variables that addressed time spent working and driving in a "typical week" were of only limited use for our schedule modeling work, for which we required more detailed (i.e. daily) information. However, we were able to use the weekly information as a check against the weekly values generated by the schedules. The variables on sleep, which could be analyzed separately for various driver types, proved more helpful because they allowed for direct comparison to results from other data sets. We applied the results from these analyses to the modeling phase of our work.

In addition, the variable on whether drivers split their off-duty time into two periods was used to inform our construction of off-duty time in the schedules. For all analyses, the variable for miles driven for work per year allowed us to separately analyze regional and long-haul drivers. The issue of the safety of inexperienced drivers was difficult to address using the New York state data because the responses were generated using bins where the level of detail at the upper end was insufficient for our purposes. Specifically, the variable uses six-month or 12-month bins up to 4 years, combines all drivers with 5-10 years of experience, and condenses all remaining levels of experience into the open-ended bin ">10 years".

5) Survey-specific issues and their resolution

There are two issues concerning the design of the New York state survey that we believe could influence the results from this data set. First, because a disproportionate number of drivers interviewed were licensed in New York (22%), and a significant number (16.5%) were licensed in Canada, there is some concern about the applicability of the results to drivers in other parts of the country. It is unclear how this would affect the data, however, so we did not alter our analysis of the data to address this issue. Second, more than one-fourth of the sample was collected at required safety inspection sites in an effort to capture a more representative sample of drivers.

(v) "Who Violates Work-Hour Rules? A Survey of Tractor-Trailer Drivers," 1992, by Elisa Braver, Carol Preusser, David Preusser, Herbert Baum, Richard Beilock and Roland Ulmer (Insurance Institute for Highway Safety)

1) Basic information

The Insurance Institute for Highway Safety (IIHS) survey was administered to 1,249 drivers at several geographically dispersed states (Connecticut, Florida, Oklahoma and Oregon) for seven days in each state between December 1990 and April 1991. The time of day of data collection was randomized and spread over a 24-hour period. Respondents were qualified to complete the survey if they reported spending at least one night away from home when driving. In an effort to screen out local drivers, potential respondents were excluded if they were driving a straight truck (the authors explain that this type of vehicle tends to be used in pickup and delivery operations). The survey was administered primarily at 24-hour truck inspection stations that had been selected based on their large size and location along a major interstate highway. Additional interviews (22%) were conducted at truck stops in all four states to mitigate the effects of potential measurement bias due to the presence of law enforcement officials at the inspection stations. These interviews were also randomized by time of day, but only until 10pm for safety reasons.

2) *Representativeness and strengths*

The survey was designed to capture a representative sample of all tractor-trailer drivers traveling along interstate highways adjacent to the truck inspection stations. One strength of the data set is its massive scale and geographic dispersion, which support a representative sample. However, the choice of inspection stations, at which almost 80% of the surveys were conducted, may serve to bias the data (except in the case of Florida, where the stations were for agricultural inspections and featured no risk of HOS enforcement). Respondents were overwhelmingly for-hire drivers in each state (78% to 87%), which is comparable to the composition of other data sets. However, the survey showed fewer than 10% owner-operators overall (range of 3% to 16% by state), which is lower than the percentage found in other studies used for this analysis.

3) *Variables*

The three variables of primary interest in the IIHS study addressed hours spent working in a week, hours spent driving in a week, and annual miles driven. Additional variables provide some information about the composition of the data set in terms of owner-operators, private carriers and for-hire drivers, as well as team drivers. The IIHS study also collected interesting information on the number of drivers who violate various HOS rules.

4) *Applications of data*

Although the IIHS survey included several potentially useful variables, we were severely limited in our ability to use them because we possessed only the study that derived from the data, not the data itself. For our purposes it was important to separately analyze several different driver subgroups based on range of operations, driver type and company type, but we were limited to the statistics presented in the IIHS study. Secondly, the bins that were used to present the data were often too large for detailed analyses and/or were not comparable to the bins and categories employed in other data sources. Thus, while we examined the IIHS results at face value, we did not consider them readily comparable to the results from other data sources. Ultimately we used the IIHS study only to generate another estimate of hours worked per week for comparison with other data sets.

5) *Survey-specific issues and their resolution*

The survey collection method relied heavily on one or two highly trafficked inspection stations along major interstate highways in each of the four states in the study. Because trucks may avoid inspections by driving around them on secondary roads, and because the "avoidance" drivers are more likely to be those who are operating in violation of HOS rules, we would expect some sampling bias from this selection method. Ultimately, because we were unable to work with the IIHS data to determine what properties influenced the results, we severely limited our reliance on its results.

(vi) "Effects of Sleep Schedules on Commercial Motor Vehicle Driver Performance," 2000, by Balkin et al. *(Walter-Reed Army Institute of Research)*

1) Basic information

The Walter Reed Commercial Motor Vehicle field study gathered sleep patterns via wrist actigraphy and self-reported sleep logs from 25 long-haul and 25 short-haul drivers over two to three weeks each. The data was entered into the Walter Reed Sleep Performance Model. A second study, which we do not discuss here, was conducted in the laboratory. Truck drivers were recruited through flyers hung in truck stops and through word-of-mouth. Participants were required to hold a commercial drivers license (CDL). Short haul and long haul drivers were differentiated based on whether they were able to return home at the end of work periods to sleep.

2) Representativeness and strengths

This study represents the most accurate information available regarding truckers' exact sleep routines by time of day. Other available datasets with information on truckers' sleep patterns are also useful to analyze different aspects of truck drivers' sleep schedules. However, these datasets are likely, to some extent, to underestimate the proportion of drivers with extreme schedules. This is because the results available do not sufficiently differentiate among types of truckers or their differing work schedules over the past 7 days. Instead, results are aggregated and summarized as if truckers' schedules were homogeneous over time and across groups. Moreover, with exception of WR, most studies ask subjects for their subjective view of how much they are sleeping, incremented in one-hour units, and do not differentiate between time in bed versus actual sleep. The strength of the WR study resides in the precise nature of its sleep measurements and the fact that they were carried out over a relatively long period of time.

3) Variables

The variables of interest in the Walter Reed study were the date of observation, the time spent on-duty and off-duty each day, and the time of day and duration of each sleep period.

4) Applications of data

We used WR primarily a basis for modeling what time sleep cycles begin in actual sleep schedules. We did not correlate these sleep schedules with the specific demographics of a driver, but did ensure that the schedules matched information derived from other data sources on schedule habits of specific driver groups. Furthermore, we do not have evidence from our other data sources that owner operators differ from company employees in terms of the proportion who get their sleep at night.

We examined data from other surveys to consider how to adjust the driver sleep patterns found in the Walter Reed field study to represent current driver schedules and driver schedules under complete compliance with current and proposed HOS rules. The various datasets available with information on truckers' sleep patterns are useful to model different aspects of a truck drivers' sleep schedule. The model schedules are likely, to some extent, to underestimate the proportion of drivers with extreme schedules. As discussed above, this is due to several factors, including insufficient differentiation among types of truckers and their varying work schedules over the course of a week.

5) Survey-specific issues and their resolution

Several observations (i.e. a single day's worth of data for a single driver) produced mathematically impossible or implausible amounts of time spent on daily activities. These observations were also marked in several ways that differentiated them from other data points in ways that led us to conclude they had been estimated. To prevent estimates from influencing our analysis, we deleted the observations.

(vii) Impact of Local/Short Haul Operations on Driver Fatigue. Task 1: Focus Groups Summary and Analysis, 1998 (Virginia Tech Focus Groups). Task 2: Field Study, 2000 (Virginia Tech Field Study) by Hanowski* et al. *(Center for Transportation Research, Virginia Polytechnic Institute and State University)

1) Basic information

The Virginia Tech Focus Groups (Task 1) were designed to collect information from truck drivers on safety issues characteristic of local and short-haul trucking and to discover the extent to which fatigue is related to those safety issues. The researchers formed 11 focus groups in five states in which 82 short haul drivers (defined as those who operate within 100 miles of home base) participated. Truck drivers were recruited through advertisements in newspapers, "cold calling" of short haul trucking companies, and arrangements made directly with company managers known to the researchers.

The Virginia Tech Field Study (Task 2) focused on analyzing the events that precede near-crash events among short haul truck drivers. The research involved a field study of 42 drivers who worked for one of two participating companies (a beverage firm and a snack food firm). Trucks employed in the study were representative of the trucks used in daily operations at both companies. Data on the drivers' wakefulness was collected from each subject over a period of two weeks using "black box" data collection systems, into which data was fed from wrist Actigraphs, video cameras, and sensors that monitored vehicle instruments.

2) Representativeness and strengths

The self-selection of the focus group participants and described informality of the sessions was a benefit for the researchers because it produced candid discussion. However, the composition of the focus groups may be biased because the recruitment effort likely resulted in a sample of drivers who have concerns about the truck driving industry, and it is unclear to what extent their responses may have been biased by their interactions with each other and the interviewers. Furthermore, six of the focus groups were organized by managers of short haul trucking operations who have contacts with the research team. These focus groups tended to have a majority of participants from the same company, or a majority who hauled the same products, and therefore may not be representative of short haul truck drivers. The primary strengths of the focus group study is that it is one of few sources of information on the short haul population, and that it employed Actigraphs, not self-reporting, to collect information on the duration and timing of sleep.

3) *Variables*

Some data was collected through a questionnaire prior to each focus group and then later through self-description during the focus group session. The data collected in these two ways provided hours worked per week, percentage of time spent driving, hours worked per day, days worked per week, and the time at which a work day usually begins. We estimated the hours worked per day for a small number of truck drivers who provided a range of working hours.

The field study provided data that gave insight into the structure of a typical short-haul driver's average work day, even though that was not the focus of the research. The results we examined were collected through the following variables – number of days worked per week, miles driven per day, number of deliveries per day, typical time at which the shift starts and ends, hours spent working, and hours spent sleeping.

4) *Applications of data*

Individual driver responses during the focus groups were recorded and published as part of the project findings, which enabled us to examine the structure of a work day and the amount of time spent driving and working per day and week. We used the anecdotal information from the focus groups to develop a better idea of how the work day of short haul drivers is structured. For example, short haul drivers pointed out that they do not take many long breaks during the work day because generally the time spent driving between pickup and delivery stops is considered "break time" from other activities that consume more of their time.

Data used as a basis for modeling daily schedules for short-haul drivers in Chapter 8 include time of day started work, average number of deliveries for beverage and snack delivery drivers from table 14 (p77), and average non-break time driving from Figure 25 (p75). Hours of work per day for short-haul drivers from the field study is used in developing changes in labor requirements under constant demand as well as modeling.

5) *Survey-specific issues and their resolution*

The data from the focus groups required a minimal amount of data cleaning to eliminate non-discrete driver responses. For example, two drivers had varying shift start times, so we deleted them from the sample when analyzing time of day work began. In addition, we estimated the hours worked per day for a small number of truck drivers who provided a range of working hours. One driver did not appear to exhibit characteristics of a short-haul driver and was dropped.

The field study showed lower amounts of sleep than we expected based on our preliminary industry research and data from the Walter Reed study of short-haul drivers. The technology used in the Field Study was similar to the wrist monitors and software employed in the Walter-Reed field study. However, in this study the technology was used to register sleep based on the time of day the driver went to bed and the time of day he or she woke up. The actual amount of sleep then was calculated based on those two data points, presumably using some percentage reduction of the total time in bed. The Walter-Reed study, in contrast, monitored sleep throughout the day, which enabled the recording of multiple bouts of sleep interspersed throughout the day. Therefore, we would expect to find that drivers in the Walter-Reed sample get more sleep than their counterparts in the Virginia Tech sample.

However, according to our preliminary research, short haul drivers get most of their sleep in one bout, off-duty, at night. To create a better comparison, we calculated the hours slept by Walter-Reed short haul drivers in the first bout only and found that this amount was more than that of the drivers in the Virginia Tech study. One plausible explanation for this persistent discrepancy is that the samples simply represent different populations. The Walter-Reed field study recruited its subjects via advertising and word of mouth, whereas the Virginia Tech subjects were all from two voluntarily participating firms (snack food and beverages), which may not represent the same population.

(viii) FMCSA 2001 Inspections and Inspections Violation Database

1) Basic information

The Federal Motor Carrier Safety Administration (FMCSA) collects motor carrier safety data from roadside inspections, crashes and compliance reviews. Information on roadside inspections was provided in two different databases – a violation file and an inspection file. Each record in the inspection file contains information on a single roadside inspection. The data contains nearly 16 million violations from roughly 7 million inspections conducted over the last four years, 1999-2002.

2) Relevant variables

Violations of hours of service and log book recording provisions.

3) Application of data & data set-specific issues

The FMCSA Violations and Inspection Database was analyzed for its relevance in determining rates of violation of current HOS provisions. The rates of violation of HOS provisions using this database in combination with the Office of Motor Carrier Census File were found not to be reliable because of sample bias problems and Record of Duty Status (RODS) log book violations.

Violation rates using the FMCSA Database may be affected by sample selection bias because drivers might avoid routes with known inspection sites or end routes just before the inspection site if they are in violation of HOS, which could decrease likelihood of finding actual violation rates. In addition, drivers who are less than 48 hours behind in their RODS book are allowed by regulation to complete the remaining hours during the inspection (§395.13(b)(3)). In theory, drivers could fill out the RODS forms only at the end of each day to cover any HOS violations and rarely be cited for an HOS violation.

Another limitation of estimating HOS violations using the FMCSA Database is that the database indicates a high violation rate for various aspects of log book record keeping. The FMCSA 2001 Inspections and Inspections Violation Database shows that 23 percent of drivers not keeping their RODS log books current, falsifying their log books, failing to retain seven days of records, or having no log books, and another 11.5 percent with other log book violations. This finding is supported by other research on log book violations. In one study, about two-thirds of drivers indicated that they sometimes drive more than they record in their log book (IIHS, 1992, p 13, Table 4). In another study, 43 percent said they sometimes, often, or always drive more often than recorded in a log book (McCartt, et al., 1998, p. 39).[14] The result of log book violations is under-representation of true current violation rates for HOS provisions.

Another limitation of the FMCSA Database is that it does not distinguish between long-haul and other drivers, who are likely to have lower violation rates (Belman, et al., 1997-1999; FMCSA, 2000).

[14] However, this percentage does not reveal what proportion at any given time are out of service (although 5.2 percent said they always drive more hours than recorded).

APPENDIX C. ADDED EXPLANATION OF ASSUMPTIONS FOR IMPACTS ON CARRIER OPERATIONS

This appendix presents details of the rationale for several important assumptions used in the calculation of the option's impacts on the carriers. The first of the two sections explains the basis of the composite measure of carrier productivity used to weight the outputs of the dispatch analysis. The second section presents the survey data used to determine the percentage of for-hire and private LH operations that are currently constrained by the HOS rules, and which are therefore represented by the dispatch analysis. The second section also shows the basis for the assumption of changes in productivity in LH operations that would occur if all drivers complied with the current HOS rules.

C.1 Composite Measure of Productivity

In the analysis of for-hire truckload carriers, the measure of driver productivity for different options must consider both the number of orders the trucks are able to deliver per week and the miles they are able to cover. The need to consider both of these measures stems from the fact that the carriers in the simulations are provided with more potential orders than they need to keep their tractors busy; thus, they can choose the orders that they can deliver most efficiently. Under different options, the carriers may choose a different mix of orders – specifically, they might choose a mix with a longer average haul under an option that allows more driving. Thus, a given option might be 12 percent more productive when measured in terms of miles driven per driver per week, but only 9 percent more productive in terms of orders delivered. In the real world, however, there is an essentially fixed mix of orders to be delivered (aside from mode shift issues, which are considered separately). If we wish to know how productive the carriers will be under the individual options, then, we need to find at least an approximate way to estimate their productivity for sets of orders that have the same average length.

With this goal in mind, we can consider the option that allows drivers to go an extra 12 percent more miles, but deliver only 9 percent more orders. Clearly, this option encourages the selection of longer orders from among those that are available. If efficiency is measured only in terms of orders, we would be ignoring the fact that the carrier is able not only to deliver 9 percent more orders with the same resources, but to skew the mix of orders toward longer hauls – they must be almost 3 percent longer on average to generate 12 percent more miles. These longer trips take longer to accomplish, and in general provide more value to the customers; if the carrier were obliged to choose shorter hauls, they would have time left over to deliver even more orders. On the other hand, if we measured efficiency solely in terms of miles per driver per week, we would exaggerate the value of the extra miles: the time it takes to deliver an order depends not only on the time it takes to drive from pick-up to delivery point, but also on the time needed to load and unload.

We consider the most appropriate measure, then, to start with the productivity as measured in terms of orders delivered, but then to adjust that measure upward by a fraction of the additional miles per order – in the present case, about 3 percent. The fraction depends on the rate at which the additional miles could, in theory, be converted into additional orders. If all of the time spent delivering an order were driving time, then additional miles could be converted directly into additional orders, and all of the 3 percent that represents additional miles per order should be added to the productivity measure. If almost all of the time spent on orders were loading and unloading time, the additional miles would not translate in many more orders at all, and only a small fraction of the 3 percent should be added to the productivity measure. In actual long-haul truckload operations, the time spent driving is considerably more than the time spent loading and unloading, so the productivity measure should be weighted toward adding a large fraction of the percentage of additional miles per order. For example, on a 600-mile trip at 50 miles per hour, with three hours of loading and another three of unloading, there would be twice as many driving hours as non-driving hours (12 as opposed to 6). Though no precise method of determining the right fraction would be appropriate for all operations, we chose the fraction two-thirds as a generally reasonable estimate of the appropriate fraction of extra miles per order to be added to the order-based productivity measure. In the example presented above, then, we would start with the 9 percent increase in productivity based on the increase in the number of orders, and then add two-thirds of the additional 3 percent miles per order. Thus, we would add 9 percent and 2 percent to yield an estimate of an 11 increase in productivity. Note that this final result is equivalent to putting one-third of the weight on the 9 percent increase in orders delivered and two-thirds on the 12 percent increase in miles, because one-third times 9 plus two-thirds times 12 equals 11.

C.2 ESTIMATION OF EXISTING LH WORK PATTERNS

The analysis of the cost impacts of complying fully with existing and proposed HOS rules required estimates of the current hours worked in excess of what is allowed, and estimates of the percentage of operations that are expected to be constrained by the rules. For both of these purposes, we relied on survey data collected by UMTIP (see Appendix B) as the largest, broadest, and most relevant data source.

Data on the hours worked per week for non-team drivers were divided into two length-of-haul categories for both for-hire operations and private carriage operations. For each of these four groups, we constructed distributions of driver hours of work over seven-day periods. For the assessment of the percentage of hours over the current limits, we assumed that the current limits allow an average of 61.25 hours of work in seven days, where 61.25 is the average number of hours per seven days that would yield 70 hours in eight days. For each group of drivers that reported working over 61.25 hours in the most recent week, we found the approximate number of hours they worked in excess of 61.25. We then summed the total number of excess hours, and compared it to the total hours worked by all of the drivers in the sample.

For the estimate of the percentage of operations that were constrained by the current rules, we took the percentage of drivers reporting hours worked per seven days above 60 hours, under the assumption that operations that required hours of work less than the current average limit of 61.25 would be little affected by the rule changes.

For both estimates, the private carriage estimates are presented with fewer significant digits due to the smaller sample sizes available. The for-hire operations showed greater work intensity than the private operations, and the operations with the longer hauls generally involved greater work intensity as well.

Exhibit C-1
Survey Results Used to Estimate Current LH Work Patterns

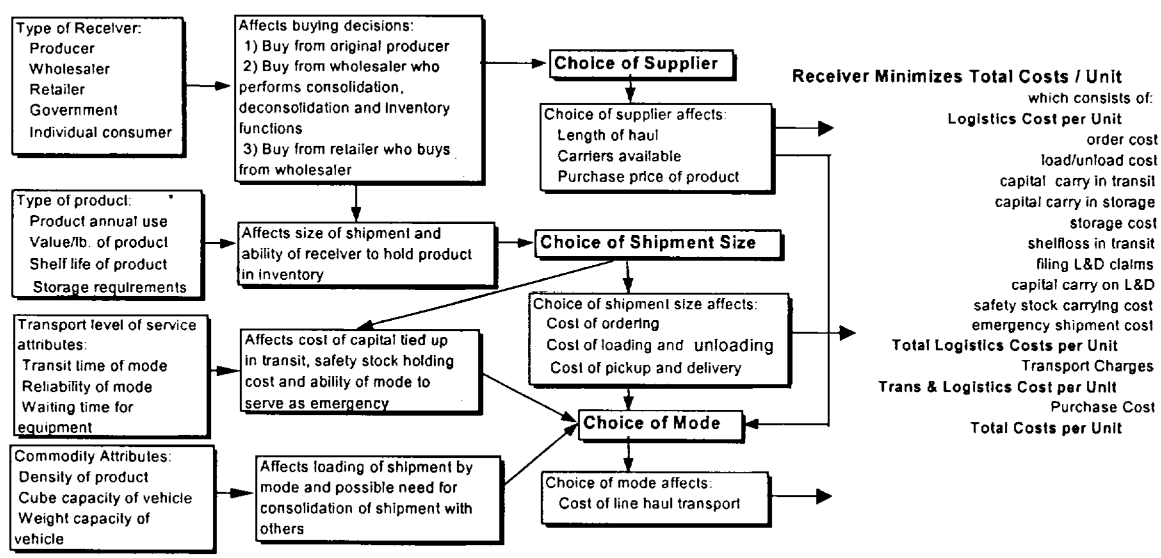
	Sample Size	Hours per Week Over 61.25	Percentage of Drivers Over 60 Hours per Week
For-hire, longer runs	332	12.7%	46.1%
For-hire, shorter runs	131	10.8%	44.3%
Private, longer runs	41	9%	32%
Private, shorter runs	19	5%	37%

Source: UMTIP Survey data, ICF Analysis

APPENDIX D.
BACKGROUND ON MODE SHIFT ANALYSIS

In determining the effects of the HOS rules on the mode split between truck and rail, we used the Logistics Cost Model (LCM) developed by Paul Roberts. The LCM is a computer model that determines the total logistics cost of transporting a product from a vendor to a receiver. It is an updated variant of models developed by Mr. Roberts for the Association of American Railroads (AAR) and the Federal Highway Administration (FHWA). The model determines the lowest cost for ordering, loading, transporting, storing, and holding a product. The shipper is assumed to select the alternative that minimizes total logistics costs. Total logistics cost in this case includes the costs occasioned by service frequency, transit time, reliability, loss and damage, spoilage and other service-related factors occurring during ordering, transport or storage. By converting all of these factors into their quantitative impacts on total logistics cost, the tradeoffs among service quality, inventory carrying and transportation charges can be addressed. The variables affecting the choices of the shipper are used to develop each of the individual cost factors listed on the right hand side of the schematic below.

Exhibit D-1
Variables Affecting Choice of Supplier, Shipment Size and Mode in Freight Transportation



These variables are used to write equations for each of the components of total logistics costs as a function of the principal choice variables (i.e., choice of supplier, choice of mode, and choice of shipment size). Changes in transport charges lead to changes in logistics costs to give the total logistics-cost change of an option. Within the model, some "shippers" make new choices and the change in mode share is calculated for the sample in the model.

D.1 Computational Steps

The model is organized to use a variety of inputs in a decision process to develop the total logistics costs of a single movement. Computational steps used by the model include the following:

- For a shipper with a given annual use of a particular product, consider alternative mode and shipment size possibilities from the vendor:
    - LTL
    - Truckload
    - Intermodal rail
    - Rail carload
- Use rate models for alternative modes to develop transportation charges to the shipper:
    - LTL
    - Truckload
    - Intermodal rail
    - Rail carload
- Develop level of service attributes for each source/mode/shipment size:
    - Frequency of service/waiting time
    - Transit time
    - Lead time reliability
    - Probability of loss and/or damage
- Combine with attributes of the product being shipped:
    - Units
    - Cube/unit
    - Packed density/unit
    - Value/unit
    - Shelf life/unit
- For each alternative source/mode/shipment size, develop the components of total logistics cost to the user of the product for:
    - Ordering
    - Loading/unloading
    - Transporting (including drayage and demurrage)
    - Capital carrying cost in transit
    - Storage
    - Capital carrying cost in storage
    - Filing loss and damage claims
    - Capital carrying on loss and damage

  - Safety stock carrying charges
  - Cost of emergency shipments
  - Perishability

- Sum to yield total logistics cost of each alternative.

- Vehicle characteristics are incorporated for various types of equipment:

  - Rail tanks, flats, reefers, boxcars, autoracks, etc.
  - Truck tanks, flats, reefers, vans, autoracks, etc..
  - Barge hoppers, tanks, etc.

D.2 DATA USED

The Logistics Cost Model is a disaggregated model. The model uses a representative sample of individual movements; the data include shipper characteristics, feasible modal alternatives, movement parameters, and commodity attributes for each movement. A disaggregate sample allows the model to examine all of these characteristics and correctly select the mode that minimizes the shipper's total logistics costs.

This project has used two different disaggregate data sources to assemble the data set used in the analysis. One is the Rail Carload Waybill Sample. These data are a sample of individual rail movements of various products moving in various car types between various origins and destinations throughout North America. Two data sets were extracted from the Waybill Sample for use in this analysis. The first was a sample of rail carload movements, excluding coal. The second was a set of intermodal rail movements. A total of 2,556 rail movements was used.

A disaggregated sample of long-haul truckload movements gathered by the Association of American Railroads in 1994 was used to establish the composition of truck shipments with regard to commodity, equipment type, and shipment size. The sample was obtained by interviews of long-haul truck drivers taken at selected truck stops throughout the U.S. The information gathered in each of the interviews included the commodity being carried, the origin, the destination, the type of truck and a variety of information about driver and vehicle. A total of 3,784 movements were eventually used, representing long-haul truckload movements throughout the nation. The data set developed by Reebie Associates, reflecting freight flows in 2000, was used to adjust the relative volume of traffic flows among origin-destination pairs to reflect current conditions.

The analysis was limited to movements of 250 miles or more. This was done on the grounds that the probability of switching traffic from truck to rail is effectively zero for moves under 250 miles. Most authorities would assert, in fact, that this probability is quite low for shipments under 500 to 700 miles. Two hundred fifty miles was chosen as a minimum, however, to ensure a thorough analysis. Data on length of freight movements from the 1997 Commodity Flow Survey (CFS) were used to adjust the disaggregate data set so that the sample of moves over 250 miles would conform to reality in the relative volumes of such traffic among city pairs.

D.3 RESULTS OF USING THE LOGISTICS COST MODEL

Results from the analysis allow us to observe which individual moves are diverted from truck as the cost of trucking goes up, and which are diverted to truck when the cost of trucking drops. For our purposes the results are aggregated and expanded to determine the increase or decrease in truck usage as a result of change in HOS policy. The table below shows the result of exercising the model over a range of increases and decreases in overall truck costs. Five cases are covered: the base case, the current level of truck cost; and: 1.0 and 2.0 percent increases from the base cost and 1.0 and 2.0 percent decreases from the base cost.

Summary of Model Runs

Observations

	Rail	Intermodal	Truck	Totals
Base Case	547	2,009	3,784	6,340
1.01*Base	552	2,070	3,718	6,340
Base*1.02	560	2,111	3,669	6,340
Base*.99	537	1,957	3,846	6,340
Base*.98	519	1,921	3,900	6,340

Tons

	Rail tons/yr	Intermodal tons/yr	Truck tons/yr	Totals
No. Tons in sample				
Base Case	2,221,349	2,710,958	8,307,492	13,239,799
1.01*Base	2,238,476	2,801,360	8,199,963	13,239,799
Base*1.02	2,260,564	2,870,570	8,108,665	13,239,799
Base*.99	2,181,121	2,623,090	8,435,588	13,239,799
Base*.98	2,128,862	2,543,339	8,567,599	13,239,799

The results of these analyses were used to estimate elasticities for the response of total truck and rail traffic to changes in overall truck costs. The ratio of the percentage change in truck shipments and tons shipped, per one percent change in truck rates, was approximately 1.4. This measure of elasticity was used, in turn, to estimate impacts on truck and rail traffic for each of the HOS rule options.

APPENDIX E.
ADDITIONAL SLEEP MODELS

This appendix describes two models relating sleep to fatigue that were assessed for use in this analysis, but not selected for use.

E.1 FATIGUE AUDIT INTERDYNE MODEL

The Fatigue Audit "InterDyne" system (FAID) was developed by the Centre for Sleep Research at the University of South Australia (Dawson et al., 1998). InterDyne is a mathematical algorithm that predicts "work-related fatigue" as a function of number of hours on duty. The model is based on timing, recency and duration of work and rest periods. Its objective is to allow companies to assess and compare previous, current and possible future work schedules in terms of predicted work related fatigue (McMahon in Hartley et al., 2000). The following factors form the conceptual basis of the FAID model:[15]

(i) Length of Shifts and Breaks

The length of shifts and breaks constitute an important factor in the determination of the risks associated with performance of a particular task. The longer the work period the greater the level of fatigue associated with the task. On the other hand, the length of the break period determines the extent to which an individual is able to obtain sleep, which is needed to reverse the effects of fatigue.

(ii) Time of Day

Fatigue accumulates faster during certain times of day over others while breaks from work also have greater potential fatigue recovery value at certain times of day. Generally, fatigue accumulates fastest at the times that we would naturally choose to sleep. Sleep has been found easiest to obtain between the hours of 2200 0800."[16]

(iii) Prior Seven-day Work History

An individual's current state of fatigue usually reflects the cumulative effect of work activities over the past seven days. The most recent days tend to have the greatest impact, while working days that are more distant will have less impact on the individual's current state of fatigue. That is, the number of hours an individual worked yesterday has a large impact on his/her fatigue state today than the number of hours worked three days ago. The number of hours s/he worked six or seven days ago has little absolute impact and much lesser impact when compared to yesterday. Work on days over seven days previous has not been found to have any measurable impact.

[15] Fletcher A., "A Discussion of Fatigue and Risk management" Centre for Sleep Research, University of South Australia, 2002.

[16] Fletcher A., "A Discussion of Fatigue and Risk management" Centre for Sleep Research, University of South Australia, 2002.

(iv) Biological limitations on Sleep

This factor emphasizes human biological limitations on sleep. For example, if a person has a week of night shifts coming up they cannot decide to sleep for 30 hours straight to offset the sleep they anticipate losing during the week ahead. Similarly, if an individual has just worked a week of night shifts s/he can generally not catch up on all of the sleep missed through a single 30-hour sleep.

(v) Inputs

The major input to the FAID is the number of hours worked. The model can be linked to an organization's roster/schedule engine such that fatigue levels can be determined in real-time. The inputs to the model include:

- An individual identification number
- Shift or work period start time
- Shift or work period finish time
- Risk level associated with tasks

For each individual, these inputs are entered into a task roster. The task roster reflects the individual's work history over any specified period. The user can specify the exact length of the work period. However, the work period must be at least two weeks in length because the information for the first working week is used in calculating the individual's current state of fatigue. The FAID enables the user to enter a routine schedule where the subject follows the exact same work schedule over a period of time, or to enter a schedule where the subject's work schedule varies from day to day. The FAID model also distinguishes between hours awake (resting or not working), hours working and hours sleeping.

In addition to the inputs above, there are three major parameters in the model that can be altered to suit the users' purpose. These three parameters are:

- Target Risk Fatigue Scores
- Sleep Propensity Targets
- Shift Details/Patterns

The assignment of target fatigue risk scores is the sole responsibility of the user. "Standard fatigue represents fatigue scores up to the maximum fatigue scores produced for a Monday to Friday 0900 to 1700 standard work week; that is, a score of 40. Moderate fatigue scores are those that are up to 200% of the maximum score produced by the standard work week, i.e., a score of 80. High fatigue scores are those that are between 200 and 250% of the maximum scores produced by the standard work week, i.e., a score of 100. Very high fatigue scores are those which are between 250 and 300% of the maximum scores produced by the standard work week, i.e., a score of 120."[17]

The sleep propensity target specifies the minimum sleep requirement for the work period. For example, if we anticipate a 14/10 cycle (14 hours on-duty /10 hours off-duty), the anticipated sleep target during the 10 hour rest period can be set to 5, 6, 7, 8, etc. The shift details/pattern specifies the time of the day associated with the beginning of each shift. For example, the morning shift could start at 0800, the afternoon shift at 1600 and night shift at 2000.

These three parameters provide the model with added flexibility in assessing different fatigue-related work scenarios.

(vi) Output

The output consists of relative fatigue scores ranging from "standard" to "extreme" for each hour of the shift schedule. This allows comparisons of different shift schedules on an hour-by-hour basis. By analyzing a theoretical or actual set of work hours using the FAID system, a score from zero to over 140 is produced.

(vii) Model Limitations

Hartley et al., 2000 critiqued the Fatigue Audit InterDyne system as not being convincing enough Additionally, Fletcher and Dawson (2000) found that predicted fatigue scores correlated poorly with performance data and only moderately with self-reported performance data for a group of locomotive drivers. The model makes no allowances for inter-individual differences, nor for differences in job demands by type of work. The InterDyne model, although on the surface may sound relevant, is in need of much more work before it would be applicable to CMV truck driving scheduling situations.

(viii) Application to Current Research Effort

The FAID model has a convenient software interface. It also has a computational advantage in the evaluation of alternative scenarios because it distinguishes between hours awake (resting or not working), hours working and hours sleeping. The model's dynamic relative risk scoring system enables it to determine acceptable thresholds of maximum fatigue score for different tasks depending on the target risk fatigue score, sleep propensity target and shift patterns.

Unlike the Psychomotor Vigilance Test scores of the Walter Reed Sleep Performance Model, however, the FAID fatigue scores are not well-suited for the analysis required in this study. The detailed information needed to evaluate alternative scheduling options under this study is neither readily available nor easy to modify and replicate.

E.2 CIRCADIAN ALERTNESS SIMULATOR

The Circadian Alertness simulator (CAS) was developed by Circadian Technologies as an integral part of its in-house consulting operations. The sleep prediction feature of CAS is based

[17] Fatigue Audit InterDyne Model: Sample description.

on the two-process model of sleep regulation. The parameters of the model for circadian and homeostatic components were determined through an optimization algorithm for data fitting, using 10,000 days of sleep-wake-work data from transportation employees working their normal duties in revenue producing operations. The model simulates alertness based on either sleep-wake-work data or work data only.

(ix) Inputs

CAS was designed to take readily available data on work-rest records and convert it into a fatigue risk score. The only required input for the CAS is work hours. The other inputs to the model are optional and they include:

- Time allotted for sleep
- Work periods
- Habitual wake-up time
- Habitual sleep length

The model is designed to function even if some data points are missing. When data is missing, as well as at the beginning of the record, assumptions are made for initial alertness values. However, at the beginning of the record and after extended periods of missing data, accuracy is compromised because of technical assumptions.[18]

(x) Outputs

CAS uses the sleep-wake cycle to simulate alertness on duty. In the final step, the computed alertness and sleep pattern is then converted into an expression of meaningful chronic fatigue risk. The model's primary outputs are fatigue level scores, sleep start/end and alertness ratings. Its optional outputs include:

- An activity histogram
- Alertness statistics
- Sleep duration statistics
- Off-duty statistics

Fatigue scores range from 0 to 100, with higher scores representing greater fatigue risk. For example, a healthy person who works a full time schedule (40hrs/week) from Monday to Friday and obtains eight regular restful hours each night would have a fatigue risk score of less than 7. On the other hand, medical emergency personnel with a repeating pattern of 36 hours on-duty followed by 12-hours off duty, would score over 90.

Alertness levels are plotted by time of day so that at any point on the alertness curve, the individual's state of alertness can be estimated at that time.

18 Draft Model Survey Summary for the Fatigue & Performance Modeling Workshop, June 13-14, 2002.

(xi) Application to Current Research Effort

The current version of the CAS does not contain an individual napping capability, circadian sleep flexibility or a minimal time interval between the occurrence of sleep and work. These features are anticipated to be included in a future version of the model.

The CAS is currently unavailable for public use because it is a proprietary product that is primarily used by Circadian Technologies for in-house consulting operations.

APPENDIX F.
MODELING SCHEDULES: DETAILED DESCRIPTION OF GENERATING LONG-HAUL DRIVER SCHEDULES AND INCREMENTS

Modeling schedules of long-haul drivers to find the percentage of crashes that are fatigue-related for each proposal involves several steps, which we address in separate sub-sections. First, as described in section F-1, we gather data on the distribution of schedule types – including hours worked per day, number of days per work week, shifting of sleep times, and other relevant information by driver types. Section F-2 describes our calculations to account for the effects on schedule rotation for long-haul drivers working heavy schedules. This includes the use of routing software. This subsection also discusses other calculations involved in estimating the extent to which schedules rotate under different proposal options. In section F-3, we discuss creating sample driver schedules that can apply to the various driver types. Section F-4 presents the results from running each driver schedule through a spreadsheet (described in Appendix G) based on the WRAIR-SPM to calculate incremental crash risk for each HOS rule option. In section F-5, we weight crash risk increments to appropriately reflect the distribution of driver schedules expected under each proposal. An interim crash risk increment for each proposal is calculated from this weighting process; the interim crash increment for each option is subtracted from the baseline crash increment, and adjusted to match productivity levels used in the cost estimates. We calculate the proportion of truck crashes in which fatigue may have played a role, and from this the percentage of all crashes that are fatigue-related. This section discusses these steps. In a later section, these modeling results are calibrated to the independent assessment of the incremental crash risk from truckers in general and the proportion of crashes estimated to be from long-haul drivers.

F.1 Distribution of Driver Schedule Types

The first step to finding the percentage of crashes that are fatigue-related for each option is determining the distribution of driver schedule types. This includes hours worked per day, number of days worked, shifting of sleep times, and other relevant information by driver types. As discussed in detail in Appendix B, UMTIP provide insufficient raw data to completely enumerate driver schedules over time. For instance, the UMTIP surveys ask drivers about hours worked over the last 24 hours rather than for a full week or for averages over time. The Walter Reed Field Study provided more information across days but is a small sample that was not randomly drawn and was insufficient to determine whether work/sleep schedules shift under current or other proposal options. We therefore gather descriptive statistics describing the distribution of schedule types from these studies in order to model 25-day schedules representative of those found in the real world.

In order to model representative schedules, we first estimate the distribution across individuals of average number of hours worked per day using the average number of hours worked in a 24-hour period for long-haul OTR drivers excluding team drivers[19] from UMTIP. The average number of hours worked is required because the relationship between truckers' schedules and sleep is estimated and available only for sleep with hours on-duty, as discussed in Section 8.4. For modeling of hours worked per day, we start by generating a large distribution of average number

[19] Team drivers are less likely to be affected by the rule changes, so we did not model them.

of hours worked per day. We generate 100 random numbers, with mean and standard deviation values taken from the UMTIP and Walter Reed data, to represent a distribution of average number of hours worked per day. The random numbers are drawn from a normal distribution with a mean value equal to the mean number of hours worked per 24-hour period for long-haul OTR drivers from UMTIP (11.37 hours per day).[20] The standard deviation of the random numbers is equal to the standard deviation across long-haul drivers in the Walter Reed Field Study of their average number of hours worked per day (1.88 hours).[21] Rather than model 100 separate schedules with only slight differences in average length of work day, we group these schedules into four bins representing average work day lengths around nine, 11, 13, and 15 hours on-duty on average in a 24-hour period (excluding full days off-duty). These bin values are chosen to divide the distribution such that the middle two values (11 and 13) represent about a third of the distribution under current compliance levels, with the remainder divided about equally between the other two values.[22] This provides the average number of hours worked per 24-hour period worked for the current HOS rules under current compliance (status quo scenario).

Next, we move from average number of hours worked per 24-hour period to number of hours worked per eight-day work period under the current HOS rules. From UMTIP, we use a frequency distribution of number of days worked in the last seven-day pay period.[23] Interviews with industry experts indicate that most OTR long-haul drivers follow an eight-day work schedule. In order to make this distribution based on seven-days apply to the current compliance baseline, we scale up the UMTIP distribution from days worked in seven to days worked in eight days. Because the mean, median, and modal OTR driver worked five days in the seven-day period, we assume that, from each group, five of every seven would work another day in an eight-day period.[24] The majority of drivers in the resulting distribution worked five to eight of the last eight days. Those who work four or fewer days in eight are not expected to be affected by changes in HOS rules. We therefore simplify the analysis and reduce the number of schedules to model by combining into one bin those who worked four or fewer days within the eight-day period. This group, which we model as working three days in eight, represents 12 percent of the trucker population. Exhibit F-1 displays the original distribution of workweek lengths as well as the rescaled and simplified distributions.

[20] See discussion in Appendix B on issues in calculating the average number of hours worked in a 24-hour period. Due to the nature of the survey's sampling methodology, this average does not include days in which the trucker is off duty for the full 24-hours.

[21] This figure excludes days in which the driver was on-duty for fewer than two hours. The UMTIP was preferred for the average number of hours worked per day due to its larger sample size combined with its more random sampling approach.

[22] Nine hours is approximately the average number of hours worked in 24-hours for truckers modeled as having worked up to 10.5 or fewer hours on average. Eleven hours is approximately the average number of hours worked in 24-hours for truckers modeled as having worked 10.5 up to 12 hours on average. Thirteen hours is approximately the average number of hours worked in 24-hours for truckers modeled as having worked 12 up to 14 hours on average, and 15 hours is approximately the average number of hours worked in 24-hours for truckers modeled as having worked 14 or more hours on average.

[23] This distribution is based on only those OTR drivers who reported fewer than 24 hours of combined work and sleep.

[24] We have no data or evidence for a negative correlation of number of days worked across weeks. For this reason, we assume that the number of days worked in the seven-day period covered in the survey represents the average for the respective proportion of the trucker population.

Exhibit F-1
Work Week Length for UMTIP and Modeled Drivers

	# Days per Week							
Driver Distribution	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
UMTIP 7-Day Distribution	1%	3%	5%	13%	35%	24%	21%	0
Distribution Rescaled to 8 Days	0%	1%	3%	7%	19%	31%	23%	15%
Simplified Distribution	0%	0%	12%	0%	19%	31%	23%	15%

Source: UMTIP and ICF Analysis

No information is available in UMTIP to estimate directly the proportion of the driver population by both hours worked in 24 hours and the number of days worked; therefore, we multiply together directly the proportions we found in the two previous steps. That is, we multiply the proportion who worked on average around nine, 11, 13, or 15 hours in 24-hours by the proportion who worked three, five, six, seven, or eight days in an eight-day schedule. This does not account for possible negative correlation between these two variables, but we do not have evidence for a strong negative relationship.[25] For clarity, in the following paragraphs, we refer to the resulting matrix of proportions of truckers working various hours-per-day and days-per-eight as the "driver schedule proportion matrix" and any individual cell within the matrix a "driver proportion cell."

The driver schedule proportion matrix is generated first to reflect current compliance levels with HOS rules.[26] This matrix is shown for the status quo in Exhibit F-2. The percentages in the cell that represents three days of work in an eight-day period and nine hours of work in 24 is simply the product of 12 percent and 14 percent, or 2 percent (after rounding for presentational purposes).

[25] In the Walter Reed field study long-haul driver data we found a small negative correlation of –0.05 between the number of hours worked and the number of days worked in a seven-day period. This would translate into a difference of less than a third of a day shorter workweek for those averaging 15 hours of work per day than those averaging 9 hours per day. For simplicity, we do not account for this correlation and do not expect it to have affected results dramatically.

[26] The degree of compliance for long-haul drivers is inferred using two different data elements from the UMTIP survey.

Exhibit F-2
Driver Schedule Proportion Matrix for Status Quo

			Days Work / 8 Days							
		Simplified Distribution Days/8	1	2	3	4	5	6	7	8
Hrs Work/ 24 Hrs	Modeled Hrs/24 Distribution	Simplified Hrs/24 Distribution								
7	1%	0%	--	--	--	--	--	--	--	--
8	3%	0%	--	--	--	--	--	--	--	--
9	10%	14%	--	--	2%	--	3%	4%	3%	2%
10	14%	0%	--	--	--	--	--	--	--	--
11	20%	34%	--	--	4%	--	7%	11%	8%	5%
12	15%	0%	--	--	--	--	--	--	--	--
13	18%	33%	--	--	4%	--	6%	10%	8%	5%
14	9%	0%	--	--	--	--	--	--	--	--
15	6%	19%	--	--	2%	--	4%	6%	4%	3%
16	4%	0%	--	--	--	--	--	--	--	--

Source: UMTIP; ICF Analysis
Percentages rounded.

The proportion matrix must be adjusted for each HOS option because different numbers of hours worked per week are allowable under each proposal. We first truncate driver proportion cells to reflect daily and weekly limits allowed under current HOS rules. That is, if a group of drivers work too many hours per day or week, we add the proportion of drivers in that cell into a permissible cell. We repeat this truncation for each proposed HOS option.

The process of truncation is that we first restrict driver proportion cells that allow too many hours per day down to the cell with the next lower number of hours that meets the daily limits. If the total number of hours per week worked for that driver proportion cell remains above that allowed under a given HOS rule option, we decrease their hours worked per day within the same number of days per eight-day period by shifting the proportion in that cell to the cell with the next lower number of hours per day working.[27] If the cell already is in the nine hours of work

[27] A preliminary test indicated that assuming a decrease in hours per day rather than days per week did not significantly influence results. One exception to this general pattern of truncation is for the present HOS rules truncated to full compliance. We did not move proportions of drivers modeled as currently above legal limits down to 13 hours daily for five days per period or 11 hours daily six days per period. Doing so would limit these drivers to 65.5 hours per eight days rather than closer to the limit of 70 hours per eight-day period. In order to consistently model all proposal options such that drivers currently out of compliance continue to work at or near their allowed limits, we moved half of these drivers to working 14 hours daily for five days and half to 12 hours daily for six days. Even though 12 hours six days per period technically is out of compliance (at 72, rather than 70 hours per period), it is close to compliance levels, and we needed to increase slightly the productivity of those in full compliance anyway, as discussed later. For that reason, this had no effect on results. We interpolated a crash risk increment for people in these two categories using a straight-line interpolation between those working 11 and 13 hours in six days per period and between those working 12 and 14 hours in five days per period. Although a third-order polynomial interpolation between those working 12 and 14 hours is a slightly better fit to the data points, we believe this probably is an over-parameterization given the limited number of data points.

per 24-hours cell and still is over the threshold, we shift the proportion in that cell to a cell in which drivers work fewer days per week.

F.2 Rolling Work/Sleep Schedules

Next, we used the modeled runs from the dispatching simulation, discussed in Chapter 5, to predict the extent to which, under the HOS rule options, drivers' primary sleeping time (and, thus, their whole sleep-work cycle) steadily moves, or rolls, over a series of days or remains fixed over time. As discussed earlier, the proposed rule options are likely to have different effects on schedules given their working and driving time limits in a 24-hour period.

We calculate the total change in time of day between the beginning and end of a working week schedule at which an OTR driver begins his sleeping break period.[28] For example, if a driver begins his route at 8 am on the first day of the route and ends at 4 am on the last day of the route before his extended (multiple-day) break, his schedule is calculated to have rolled backwards by four hours. For the current rule as followed in the real world, survey data indicates that about half the drivers currently find the time of their primary sleeping bout to shift over nights.[29] The threshold at which we considered a schedule as qualifying as having work-sleep cycles that rolled is a difference of at least two hours over a route for a backward-rolling schedule and three hours over a route for a forward-rolling schedule. Preliminary analysis suggested that less than two hours change in sleeping time over a driving route was insufficient to qualify as a significant schedule change in terms of model results. Because initial tests of the model indicated that a schedule that rolls forward adds about two-thirds of the incremental crash probability as a schedule rolling backwards, we set the forward-rolling threshold equivalent to three hours. For proposals for which some schedules rolled forward and others backwards in time, we add together the number exceeding the respective thresholds and count them all as rolling the same direction. We analyzed the likelihood of rolling separately for each proposal and for regional and long haul operations. We also measure separately the number of hours a schedule rolls in order to down-weight schedules that roll for fewer hours than modeled.[30]

For the current rule fully enforced, we found three of 13 regional schedules and seven of 11 long-haul to shift. The majority of these were rolling backwards. The regional schedules rolled

[28] We were unable to use this method for the second and subsequent weeks of a long route output from RoutePro due to limitations in the program.

[29] We arrived at a value of one half due to responses from two surveys. In the Crum survey, drivers responded to a question about how often they sleep at night – always, frequently, sometimes, rarely, and never. Forty percent of the respondents indicated they sometimes sleep at night – indicating a schedule that changes enough that they roll into or out of the night time period. We combined 40 percent with a third of the respondents who answered that they frequently (27 percent) or rarely (12 percent) sleep at night to arrive at a total of 53 percent of drivers schedules shifting under HOS rules as currently followed. The DFACS survey (Abrams, *et al.*, 1997) asks drivers when began their most recent and prior main sleep as well as when they expect to begin their next main sleep period. Fifty-four percent of respondents with valid answers for all three questions indicated that the beginning of their sleep periods changed (or was expected to change) by at least 1.5 hours between the first and second or second and third nights or both and 48 percent responded a change of at least 2 hours. Although three nights represent the sleep periods for only about half of an average six days working in an eight day period, we assume that the proportion of schedules that roll would remain about 50 percent at the end of the period. Other approaches to analyzing this question using DFACS led to a similar conclusion.

[30] As discussed later, for simplicity, we model only one set of rolling schedules at the maximum number of hours rolling expected for schedules.

on average two hours and the long-haul over ten hours over the driving period. These driving periods varied in their length depending on the limits for each proposal and trip lengths for the driver types. (See mode shift analysis for details.) We assume that the proportion of OTR drivers is split evenly between regional and long-haul companies[31] and combine the calculated proportion of regional and long-haul drivers whose schedules roll into an overall weighted average. That is, even though we do not expect all of the drivers with sleeping times that roll to shift by a total of 10 hours, for modeling purposes we calculate a weighted proportion that would be equivalent to the proportion whose sleep periods would shift backwards by ten hours. For the current rule fully enforced, the result is a weighted average of 34 percent of drivers rolling backwards an average of 10 hours (given a five-day route).

Exhibit F-3
Generation of Proportion of Schedules that Roll

	Current Rules, Fully Enforced		PATT		ATA		FMCSA	
Data element	Long-Haul	Regional	Long-Haul	Regional	Long-Haul	Regional	Long-Haul	Regional
# of schedules	11	13	10	8	10	10	10	13
# of schedules that roll	7	3	5	3	9	9	7	2
% rolling	64%	23%	50%	38%	90%	90%	70%	15%
# of hours roll	10	2	2	1.5	6	6	3	2
% rolling (relative to rolling 10 hours)*	64%	5%	10%	6%	54%	54%	21%	3%
% of total population	50%	50%	50%	50%	50%	50%	50%	50%
Overall relative % rolling*	34%		8%		54%		12%	
*This percentage is relative to a hypothetical option in which all schedules roll by 10 hours.								
The number of hours schedules roll forward are treated as equivalent to half that of rolling back.								

Source: ICF Analysis, RoutePro Simulations

For the PATT rule, we found three of eight regional schedules and five of ten long-haul roll backwards. The regional schedules rolled on average three hours forward and the long-haul two hours backwards.[32] For PATT, the result is a weighted average of 8 percent of drivers rolling backwards an average of 10 hours. For the FMCSA proposal, we found two of eight regional schedules and seven of ten long-haul rolling backwards.[33] On average, the regional schedules rolled three hours forward (which we model as equivalent to two hours backwards, as discussed previously) and the long-haul two hours backwards. For FMCSA, the result is a weighted average of 13 percent of drivers rolling backwards an average of 10 hours.

[31] An estimate, based off internal estimates of the motor carrier population, suggests that between 48 and 51 percent of all tractors used for routes at least 150 miles in length cover 700 or more miles in their routes. This calculation assumes that companies within each fleet size category ("tractor size class") average halfway between the minimum and maximum number of tractors for that size class. For the largest size class (500+ tractors), this assumes between 500 and 2,000 tractors per company. The same calculation for VMT results in a similar proportion.

[32] In order to reduce the total number of schedules modeled, we have modeled the regional PATT schedules as rolling backwards 1.5 hours rather than preparing separate schedules that would mimic schedules rolling forward under PATT (which would differ from those rolling forward under ATA).

[33] This includes two schedules rolling backwards nearly two hours.

For the ATA proposal, the results were not expected to differ between regional and long-haul drivers in terms of schedule rolling because there is no differentiation in the ATA option between hours working and driving. We found nine of ten long-haul routes with work-sleep cycles that rolled forwards an average of six hours. The result is a weighted average of 54 percent of drivers rolling forwards an average of 10 hours.

F.3 CREATING SAMPLE DRIVER SCHEDULES AS SPREADSHEET INPUTS

In this section, we set up model schedules representing drivers from each driver proportion cell for input into the Sleep/Performance spreadsheet. Two types of schedules are modeled – those in which the work-sleep cycle continues to shift over a series of days and those in which they remain fixed over time. Schedules that roll both backward and forward are modeled. It is not possible to simulate the full variation in how sleeping schedules change over the course of a few weeks, and preliminary runs indicated that modeling random variation in sleep times would not make substantial differences in model outputs and results.[34]

(i) Non-Rolling Schedules

We model each non-rolling work schedule as beginning with a sleep period centered at 11 pm – around the ideal time for a driver's circadian rhythm.[35] This is followed by an hour for the driver to wake and eat and then the appropriate number of hours on-duty for that driver cell (9, 11, 13, or 15 hours). The exception to this set of non-rolling schedules is for the ATA proposal. For schedules for which drivers work 13 to 15 hours, we model their seven-day schedules as five or 4.66 days long to serve as even comparisons for the forward rolling schedules discussed in paragraphs that follow. The first hour for all modeled schedules is non-driving work. This is followed by a regular pattern of four hours of driving and a one-hour break until a threshold number of driving hours is reached.[36] The threshold is calculated as the total number of hours driving per day required over a six-day period to reach the average ratio of hours driven to total hours worked (0.69) found from OTR truckers in the UMTIP data.[37] After the threshold of

[34] Preliminary analysis indicated that modeling variation in daily sleeping schedules (but that have a constant average) that are centered at the optimal time for circadian rhythms leads to a modeled raw (before calibration, discussed later) incremental crash risk increased of about 2 percent. Adding variation in sleeping schedules that are centered at the worst time for circadian rhythms leads to an incremental crash risk increase of only 0.1 percent. We simplify by modeling a consistent amount of time of sleep. This simplification decreases slightly estimates for all rule options but is not expected to affect relative difference between them. However, due to analytical and computational limitations with the routing software, we are not able to gauge with sufficient accuracy the extent to which any of the rules is more likely than others to create small random variations in sleep schedules. The extent to which schedules roll is expected to overwhelm the crash increment from smaller perturbations.

[35] For simplification, we do not model naps during the day. Preliminary analysis indicates that doing so produces only minor differences in results from modeling total sleep time as occurring all at night. (Because the Walter Reed Field Study data is based on total sleep in 24 hours, modeling naps would be equivalent to moving sleep from a single sleep bout to two bouts.) For 1.5 hours of nap time at 3 pm every third day, which represents the average found in the Crum data set, there is an additional 1.2 percent raw crash increment before calibration.

[36] This pattern varies only slightly from that used in the Route Pro runs but should not affect results.

[37] This ratio is found when dropping respondents for whom more than 24 hours are accounted. The ratio varies only slightly when including the other respondents and normalizing their responses, but this should not affect greatly the results in terms of the relative differences across options. For simplicity, the same ratio of hours of driving to total work hours is used even for schedules for which drivers work fewer or more days per week. This approach affects rolling schedules but not the non-rolling schedules.

driving hours is reached, the workday continues with any additional non-driving work time until the total number of hours of work is reached.38 Sleep after workdays also is centered at the ideal time for circadian rhythms. Drivers are modeled as working three, five, six, seven, or eight days per eight-day period. For days during which the driver is not modeled to work, sleep time is modeled as 8.25 hours the day off, and no driving time is modeled.[39]

An example of a modeled driver schedule for input into the spreadsheet is shown in Exhibit F-4. This represents a schedule under the current HOS rules in which the driver works 13 hours daily for six days of each eight-day schedule. Periods in which the trucker is driving are coded by a letter "D", and those in which the driver is sleeping are coded with a "1." All other periods are either working but not driving or not working but not sleeping. Although these periods are differentiated in constructing the model schedules, they are both coded with a "0" because the crash increment is calculated only for the periods in which the trucker is driving. In addition, non-driving time that is not used for sleeping does not exhibit a restorative effect, as discussed in Appendix F. While these activities differ for a trucker, they are handled identically by the model, and thus are both coded with a "0." The first column displays time of day beginning with 10 pm. The schedule is arranged this way for presentational purposes to show primary sleeping hours at the top of the schedule, but this has no effect on the model itself. The second column is the first (arbitrarily defined) 24 hour "day" of a schedule. Subsequent days, are shown in the following columns beginning at 10 pm 24 hours after the previous day. Exhibit F-4 is a schedule in which the sleeping period is stable and does not roll, as seen by the uniform beginning time for sleep. In this example, every third night of sleep on duty is 15 minutes shorter than the other nights in order to reach an average of 6.7 hours per night over the nights working, which is the amount predicted from the equation discussed in Section 8.4. The seventh and eighth nights of sleep are the days off-duty, and therefore are 8.25 hours long followed by no hours driving those days.

[38] Another difference between the ATA and other schedules is that we model an extra two hours of driving time only for long-haul (not regional) truckers under ATA in line with our Route Pro modeling. They are able to drive these extra two hours because ATA does not distinguish between driving and non-driving hours and because long-haul drivers will spend less time in loading and waiting activities than regional drivers will.

[39] The sleep equation, described earlier derived from the Walter Reed Field Study, predicts 8.16 hours of sleep on non-working days, which we round up to 8.25 hours of sleep because our spreadsheet model's level of precision is 15 minute increments

Exhibit F-4
Spreadsheet Driver Schedule:
(Current Rules, 13 Hours On-Duty, 6 Day Work Cycle, Stable)

	Day in Driver Schedule																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
10:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11:00 PM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11:15 PM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11:30 PM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11:45 PM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12:00 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12:15 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12:30 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12:45 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1:00 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1:15 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1:30 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1:45 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2:00 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2:15 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2:30 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2:45 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3:00 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3:15 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3:30 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3:45 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4:00 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4:15 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4:30 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4:45 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5:00 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5:15 AM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5:30 AM	1	1	0	1	1	0	1	1	1	[illegible]	0	1	1	0	1	1	1	1	0	1	1	0	1	1	1
5:45 AM	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0
6:00 AM	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0
6:15 AM	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0
6:30 AM	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0
6:45 AM	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0
7:00 AM	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0
7:15 AM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:30 AM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:45 AM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:00 AM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
8:15 AM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
8:30 AM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
8:45 AM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
9:00 AM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
9:15 AM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
9:30 AM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
9:45 AM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
10:00 AM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
10:15 AM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
10:30 AM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
10:45 AM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
11:00 AM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
11:15 AM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
11:30 AM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
11:45 AM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
12:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1:00 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
1:15 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
1:30 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
1:45 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
2:00 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
2:15 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
2:30 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
2:45 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
3:00 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
3:15 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
3:30 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
3:45 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
4:00 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
4:15 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
4:30 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
4:45 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
5:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6:00 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
6:15 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
6:30 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
6:45 PM	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D	D	D	D	D	D	0	0	D
7:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9:00 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9:15 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9:30 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9:45 PM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: ICF Consulting Analysis

(ii) Rolling Schedules

In accord with *a priori* expectations and the findings for the current compliance scenario, we model schedules with sleeping periods that roll backwards as rolling two hours per night. For simplicity, we model only one set of schedules rolling backwards. Rolling schedules also all begin at 11 pm with a sleep period centered around the ideal time for a driver's circadian rhythm. Modeled sleep periods are followed by an hour for the driver to wake and eat and then the appropriate number of hours on-duty for that driver cell.

An example of a modeled driver schedule that rolls backwards two hours daily is shown in Exhibit F-5. This represents a schedule under the current HOS rules in which the driver works 13 hours daily for six days of each eight-day schedule. The schedule is coded the same way as with the previous schedule shown. The pattern differs from that found in Exhibit F-4 in two primary ways. First, the sleeping period begins two hours earlier every night. Second, the number of hours sleeping or driving in a 24-hour period differs by day.

Schedules that shift by two hours are complicated by having combined sleep-work cycle lengths of 22 hours (that is, 24 minus 2 hours). The relationship between sleep and hours on-duty discussed in 8.4 is based on a 24 hour time period and not a 22 hour period. In addition, the proposal rules are measured in 24-hour periods. Because the cycles are only 22 hours long, more than one period of sleeping (or driving shift) may be included in any arbitrarily-defined "day." For example, the first night of sleep in Exhibit F-4 begins at 11 pm. The second begins at 9 pm, which is displayed at the bottom of the first column – within the first 24-hour "day." To compensate for variation across days, we calculate the amount of sleep for each 22-hour period such that the average amount of sleep in a 24-hour period (across the six days working in the first eight-day "week") matches the predicted amount of sleep estimated by the equation in 8.4. More simply, we calculate the amount of sleep in a 22-hour cycle such that the total amount of sleep in the first six working (24-hour) days is approximately[40] (result from equation in 8.4) × 6. This formula is adjusted for the number of days working in an eight-day cycle.

The number of hours driving in a 22-hour cycle is back-calculated similarly. For rolling schedules, the number of hours driven per 22-hour sleep-work cycle is back-calculated from the total number of hours driving required over a six-day period (24-hour per day) to reach the average amount of driving expected in six days. This target is found by multiplying the ratio of hours driven to total hours worked found from OTR truckers in the UMTIP data (.69) by the total number of hours worked in six days (at nine, 11, 13, or 15 total hours worked per 24-hour day).[41] In Exhibit F-4, the driver drives an average of 9 hours per day over the six days ($13 \times 0.69 = 9$). Therefore, while the total number of hours worked, driven, and slept in a 22-hour sleep-work cycle remains constant across cycles, the amount of work, driving, or sleep will not remain constant across fixed 24-hour days. They will also differ between the non-rolling and rolling schedules.

[40] The result is approximate due to the spreadsheet's precision at 15-minute increments. As with the non-rolling schedules, rolling schedules repeat alternating patterns of sleep or driving if an uneven number of 15 minute periods are required to reach the goal.

[41] Six days is chosen as it is the median number of days worked currently in an eight day schedule.

As with the non-rolling schedules, drivers are modeled as working three, five, six, seven, or eight days per eight day period. Schedules continue to roll backwards until the end of work week, when drivers return to a normal sleep schedule. As with the non-rolling schedules, work hours follow a regular pattern of four hours of driving followed by a one-hour break until a threshold number of driving hours is reached.

In Exhibit F-5, as with the non-rolling schedule in Exhibit F-4, every third night of sleep on duty is 15 minutes shorter than the other nights in order to reach an average of 6.6 hours per night over the six nights in the first working cycle, which is the amount predicted from the equation discussed in Section 8.4. The seventh and eighth nights of sleep are off-duty, and therefore are 8.25 hours long followed by no hours driving those days.

Exhibit F-5
Spreadsheet Driver Schedule:
(Current Rules, 13 Hours On-Duty, 6 Day Work Cycle, Rolling Backwards 2 Hours)

	Day in Driver Schedule																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
10:00 PM	0	1	1	1	0	D	D	0	0	1	1	1	0	D	D	0	0	1	1	1	0	D	D	0	0
10:15 PM	0	1	1	1	0	D	D	0	0	1	1	1	0	D	D	0	0	1	1	1	0	D	D	0	0
10:30 PM	0	1	1	1	0	D	D	0	0	1	1	1	0	D	D	0	0	1	1	1	0	D	D	0	0
10:45 PM	0	1	1	0	D	D	D	0	0	1	1	0	D	D	D	0	0	1	1	0	D	D	D	0	0
11:00 PM	1	1	1	0	D	D	1	1	1	1	1	0	D	D	1	1	1	1	1	0	D	D	1	1	1
11:15 PM	1	1	1	0	D	D	1	1	1	1	1	0	D	D	1	1	1	1	1	0	D	D	1	1	1
11:30 PM	1	1	1	0	D	D	1	1	1	1	1	0	D	D	1	1	1	1	1	0	D	D	1	1	1
11:45 PM	1	1	1	0	D	D	1	1	1	1	1	0	D	D	1	1	1	1	1	0	D	D	1	1	1
12:00 AM	1	1	1	0	D	D	1	1	1	1	1	0	D	D	1	1	1	1	1	0	D	D	1	1	1
12:15 AM	1	1	1	0	D	D	1	1	1	1	1	0	D	D	1	1	1	1	1	0	D	D	1	1	1
12:30 AM	1	1	0	0	D	D	1	1	1	1	0	0	D	D	1	1	1	1	0	0	D	D	1	1	1
12:45 AM	1	1	0	D	D	0	1	1	1	1	0	D	D	0	1	1	1	1	0	D	D	0	1	1	1
1:00 AM	1	1	0	D	D	0	1	1	1	1	0	D	D	0	1	1	1	1	0	D	D	0	1	1	1
1:15 AM	1	1	0	D	D	0	1	1	1	1	0	D	D	0	1	1	1	1	0	D	D	0	1	1	1
1:30 AM	1	1	0	D	D	0	1	1	1	1	0	D	D	0	1	1	1	1	0	D	D	0	1	1	1
1:45 AM	1	1	0	D	D	D	1	1	1	1	0	D	D	D	1	1	1	1	0	D	D	D	1	1	1
2:00 AM	1	1	0	D	D	D	1	1	1	1	0	D	D	D	1	1	1	1	0	D	D	D	1	1	1
2:15 AM	1	1	0	D	D	D	1	1	1	1	0	D	D	D	1	1	1	1	0	D	D	D	1	1	1
2:30 AM	1	1	0	D	D	D	1	1	1	1	0	D	D	D	1	1	1	1	0	D	D	D	1	1	1
2:45 AM	1	0	D	D	0	D	1	1	1	0	D	D	0	D	1	1	1	0	D	D	0	D	1	1	1
3:00 AM	1	0	D	D	0	D	1	1	1	0	D	D	0	D	1	1	1	0	D	D	0	D	1	1	1
3:15 AM	1	0	D	D	0	D	1	1	1	0	D	D	0	D	1	1	1	0	D	D	0	D	1	1	1
3:30 AM	1	0	D	D	0	D	1	1	1	0	D	D	0	D	1	1	1	0	D	D	0	D	1	1	1
3:45 AM	1	0	D	D	D	D	1	1	1	0	D	D	D	D	1	1	1	0	D	D	D	D	1	1	1
4:00 AM	1	0	D	D	D	D	1	1	1	0	D	D	D	D	1	1	1	0	D	D	D	D	1	1	1
4:15 AM	1	0	D	D	D	D	1	1	1	0	D	D	D	D	1	1	1	0	D	D	D	D	1	1	1
4:30 AM	1	0	D	D	D	D	1	1	1	0	D	D	D	D	1	1	1	0	D	D	D	D	1	1	1
4:45 AM	0	D	D	0	D	D	1	[illegible]	0	D	D	0	D	D	1	1	0	D	D	0	D	D	1	1	0
5:00 AM	0	D	D	0	D	D	1	[illegible]	0	D	D	0	D	D	1	1	0	D	D	0	D	D	1	1	0
5:15 AM	0	D	D	0	D	D	1	[illegible]	0	D	D	0	D	D	1	1	0	D	D	0	D	D	1	1	0
5:30 AM	0	D	D	0	D	D	1	[illegible]	0	D	D	0	D	D	1	1	0	D	D	0	D	D	1	1	0
5:45 AM	0	D	D	D	D	0	1	[illegible]	0	D	D	D	D	0	1	1	0	D	D	D	D	0	1	1	0
6:00 AM	0	D	D	D	D	0	1	[illegible]	0	D	D	D	D	0	1	1	0	D	D	D	D	0	1	1	0
6:15 AM	0	D	D	D	D	0	1	[illegible]	0	D	D	D	D	0	1	1	0	D	D	D	D	0	1	1	0
6:30 AM	0	D	D	D	D	0	1	[illegible]	0	D	D	D	D	0	1	1	0	D	D	D	D	0	1	1	0
6:45 AM	D	D	0	D	D	D	1	1	D	D	0	D	D	D	1	1	D	D	0	D	D	D	1	1	D
7:00 AM	D	D	0	D	D	D	1	1	D	D	0	D	D	D	1	1	D	D	0	D	D	D	1	1	D
7:15 AM	D	D	0	D	D	0	0	0	D	D	0	D	D	0	0	0	D	D	0	D	D	0	0	0	D
7:30 AM	D	D	0	D	D	0	0	0	D	D	0	D	D	0	0	0	D	D	0	D	D	0	0	0	D
7:45 AM	D	D	D	D	0	0	0	0	D	D	D	D	0	0	0	0	D	D	D	D	0	0	0	0	D
8:00 AM	D	D	D	D	0	0	0	0	D	D	D	D	0	0	0	0	D	D	D	D	0	0	0	0	D
8:15 AM	D	D	D	D	0	0	0	0	D	D	D	D	0	0	0	0	D	D	D	D	0	0	0	0	D
8:30 AM	D	D	D	D	0	0	0	0	D	D	D	D	0	0	0	0	D	D	D	D	0	0	0	0	D
8:45 AM	D	0	D	D	D	0	0	0	D	0	D	D	D	0	0	0	D	0	D	D	D	0	0	0	D
9:00 AM	D	0	D	D	D	0	0	0	D	0	D	D	D	0	0	0	D	0	D	D	D	0	0	0	D
9:15 AM	D	0	D	D	0	0	0	0	D	0	D	D	0	0	0	0	D	0	D	D	0	0	0	0	D
9:30 AM	D	0	D	D	0	0	0	0	D	0	D	D	0	0	0	0	D	0	D	D	0	0	0	0	D
9:45 AM	D	D	D	0	0	0	0	0	D	D	D	0	0	0	0	0	D	D	D	0	0	0	0	0	D
10:00 AM	D	D	D	0	0	0	0	0	D	D	D	0	0	0	0	0	D	D	D	0	0	0	0	0	D
10:15 AM	D	D	D	0	0	0	0	0	D	D	D	0	0	0	0	0	D	D	D	0	0	0	0	0	D
10:30 AM	D	D	D	0	0	0	0	0	D	D	D	0	0	0	0	0	D	D	D	0	0	0	0	0	D
10:45 AM	0	D	D	D	0	0	0	0	0	D	D	D	0	0	0	0	0	D	D	D	0	0	0	0	0
11:00 AM	0	D	D	D	0	1	0	0	0	D	D	D	0	1	0	0	0	D	D	D	0	1	0	0	0
11:15 AM	0	D	D	0	0	1	0	0	0	D	D	0	0	1	0	0	0	D	D	0	0	1	0	0	0
11:30 AM	0	D	D	0	0	1	0	0	0	D	D	0	0	1	0	0	0	D	D	0	0	1	0	0	0
11:45 AM	D	D	0	0	0	1	0	0	D	D	0	0	0	1	0	0	D	D	0	0	0	1	0	0	D
12:00 PM	D	D	0	0	0	1	0	0	D	D	0	0	0	1	0	0	D	D	0	0	0	1	0	0	D
12:15 PM	D	D	0	0	0	1	0	0	D	D	0	0	0	1	0	0	D	D	0	0	0	1	0	0	D
12:30 PM	D	D	0	0	0	1	0	0	D	D	0	0	0	1	0	0	D	D	0	0	0	1	0	0	D
12:45 PM	D	D	D	0	0	1	0	0	D	D	D	0	0	1	0	0	D	D	D	0	0	1	0	0	D
1:00 PM	D	D	D	0	1	1	0	0	D	D	D	0	1	1	0	0	D	D	D	0	1	1	0	0	D
1:15 PM	D	D	0	0	1	1	0	0	D	D	0	0	1	1	0	0	D	D	0	0	1	1	0	0	D
1:30 PM	D	D	0	0	1	1	0	0	D	D	0	0	1	1	0	0	D	D	0	0	1	1	0	0	D
1:45 PM	D	0	0	0	1	1	0	0	D	0	0	0	1	1	0	0	D	0	0	0	1	1	0	0	D
2:00 PM	D	0	0	0	1	1	0	0	D	0	0	0	1	1	0	0	D	0	0	0	1	1	0	0	D
2:15 PM	D	0	0	0	1	1	0	0	D	0	0	0	1	1	0	0	D	0	0	0	1	1	0	0	D
2:30 PM	D	0	0	0	1	1	0	0	D	0	0	0	1	1	0	0	D	0	0	0	1	1	0	0	D
2:45 PM	D	D	0	0	1	1	0	0	D	D	0	0	1	1	0	0	D	D	0	0	1	1	0	0	D
3:00 PM	D	D	0	1	1	1	0	0	D	D	0	1	1	1	0	0	D	D	0	1	1	1	0	0	D
3:15 PM	D	0	0	1	1	1	0	0	D	0	0	1	1	1	0	0	D	0	0	1	1	1	0	0	D
3:30 PM	D	0	0	1	1	1	0	0	D	0	0	1	1	1	0	0	D	0	0	1	1	1	0	0	D
3:45 PM	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0
4:00 PM	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0
4:15 PM	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0
4:30 PM	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0
4:45 PM	D	0	0	1	1	0	0	0	D	0	0	1	1	0	0	0	D	0	0	1	1	0	0	0	D
5:00 PM	D	0	1	1	1	0	0	0	D	0	1	1	1	0	0	0	D	0	1	1	1	0	0	0	D
5:15 PM	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0
5:30 PM	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0
5:45 PM	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0
6:00 PM	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0
6:15 PM	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0
6:30 PM	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0
6:45 PM	0	0	1	1	0	D	0	0	0	0	1	1	0	D	0	0	0	0	1	1	0	D	0	0	0
7:00 PM	0	1	1	1	0	D	0	0	0	1	1	1	0	D	0	0	0	1	1	1	0	D	0	0	0
7:15 PM	0	1	1	1	0	D	0	0	0	1	1	1	0	D	0	0	0	1	1	1	0	D	0	0	0
7:30 PM	0	1	1	1	0	D	0	0	0	1	1	1	0	D	0	0	0	1	1	1	0	D	0	0	0
7:45 PM	0	1	1	1	0	D	0	0	0	1	1	1	0	D	0	0	0	1	1	1	0	D	0	0	0
8:00 PM	0	1	1	1	0	D	0	0	0	1	1	1	0	D	0	0	0	1	1	1	0	D	0	0	0
8:15 PM	0	1	1	1	0	D	0	0	0	1	1	1	0	D	0	0	0	1	1	1	0	D	0	0	0
8:30 PM	0	1	1	1	0	D	0	0	0	1	1	1	0	D	0	0	0	1	1	1	0	D	0	0	0
8:45 PM	0	1	1	0	D	D	0	0	0	1	1	0	D	D	0	0	0	1	1	0	D	D	0	0	0
9:00 PM	1	1	1	0	D	D	0	0	[illegible]	1	1	0	D	D	0	0	1	1	1	0	D	D	0	0	[illegible]
9:15 PM	1	1	1	0	D	D	0	0	[illegible]	1	1	0	D	D	0	0	1	1	1	0	D	D	0	0	[illegible]
9:30 PM	1	1	1	0	D	D	0	0	[illegible]	1	1	0	D	D	0	0	1	1	1	0	D	D	0	0	[illegible]
9:45 PM	1	1	1	0	D	D	0	0	[illegible]	1	1	0	D	D	0	0	1	1	1	0	D	D	0	0	[illegible]

Source: ICF Consulting Analysis

ATA Schedules

The modeling approach was similar for the ATA option in terms of back-calculating the number of hours driving and sleeping. For those driver cells for which people currently are working well below the ATA daily limits – those working on average nine or 11 hours per 24-hours, however, we would not expect forward rolling cycles. We model these drivers using the same schedules as those rolling backwards.

We also would expect some truckers under the ATA option to have schedules intense enough that they we expect their sleep-work cycles to roll forward. We model this as occurring for drivers working on average 13 or 15 hours per 24-hours. In those cases, a driver can work only about five sleep-work cycles before one reaches 70 hours at 13 hours per cycle or 4.67 cycles if working 15 hours per cycle. For these drivers, we model schedules of 3 or 4.66 cycles for those averaging 15 hours of work per cycle and 3 or 5 cycles for those averaging 15 hours of work per cycle.

For ATA, we distinguish between drivers who work for regional and those working for long-distance haulers. As discussed in Section 5.1, "long-haul" drivers can be divided into those who run relatively shorter routes of less than one to two days in length that one could classify as of a regional nature and those who run longer multiple-day routes of a more national nature. For the longer-haul operations, loading and unloading generally are not in the same work shift. Therefore, the impact of the on-duty time required for this work is diminished, as more of the on-duty time can be used for driving. However, this increase in productivity is accompanied by more time behind the wheel in a day, increasing both the average level of fatigue for these drivers as well as total exposure on the road. To account for this extra productivity for longer-haul operations as captured in the cost analysis as well as in the survey data, we replace two hours per 24-hours of non-driving work with two hours of driving for long-distance drivers.

A final distinction we make among schedules under the ATA option is to model differently those who work about 90 hours per week. This extra productivity allowed under the ATA rules is reflected in the Route Pro runs and in the cost analysis. We therefore reflect this productivity in the benefits analysis. At the end of the cycle, we model the drivers who work less than 90 hours as having the time to reset their sleep schedule by not working the remainder of the seven-day period and returning to optimal evening sleep schedules until their next week. For those who work 90 hours a week, their high rate of productivity only is possible if they begin their next work cycle immediately after finishing the 34 hours required in the reset provision of the multi-day rules. We model them as having two sleep cycles – one starting soon after finishing their last work cycle and the second ending two hours before starting a new work cycle.[42] These drivers working about 90 hours a week, while more productive, also are expected to have higher crash risk increments. We call work weeks in which the work cycles do not allow driver schedules to reset their sleep time "hard" rolling schedules, while those that do we call "soft" rolls.

[42] We model the second sleep period this way because it reduces crash risk relative to a schedule in which their second sleep period occurs at the optimal time for their circadian rhythm. This is true because it decreases time between the sleep period and the time they drive.

Exhibit F-6 provides an example of a "hard" rolling schedule for a trucker working for a regional carrier. The schedule differs from Exhibit F-5 because it rolls forward two hours, requiring the adjustment described above for the proper number of hours sleeping and driving per cycle. In addition, the driver begins driving immediately after his required break period ends. In Exhibit F-6, this occurs on day seven at 7:45 pm. A "hard" rolling schedule for a national, long-haul carrier would differ from this schedule only by the addition of two hours more driving in lieu of non-driving work at the end of each "day's" driving.

Exhibit F-6
Spreadsheet Driver Schedule:
(Current Rules, 13 Hrs On-Duty, 6 Day Cycle, "Hard" Roll Forward 2 Hrs, Regional OTR)

Day in Driver Schedule

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
10:00 PM	0	0	0	D	D	D	0	D	D	0	7	7	7	7	0	0	D	D	D	0	D	D	0	7	7
10:15 PM	0	0	0	D	D	D	0	D	D	0	7	7	7	7	0	0	D	0	D	0	D	D	0	7	7
10:30 PM	0	0	0	D	0	D	0	D	D	0	7	7	7	7	0	0	D	0	D	0	D	D	0	7	7
10:45 PM	0	0	0	D	0	D	0	D	D	0	7	7	7	7	0	0	D	0	D	0	0	D	D	7	7
11:00 PM	7	0	0	D	0	D	0	D	D	0	7	7	7	7	0	0	0	0	D	0	0	D	D	0	7
11:15 PM	7	0	0	0	0	D	0	D	D	0	7	7	7	7	0	0	0	D	D	0	0	D	D	0	7
11:30 PM	7	0	0	0	D	D	0	D	D	0	7	7	7	7	0	0	0	D	D	0	0	D	D	0	7
11:45 PM	7	0	0	0	D	D	0	0	[illegible]	D	0	7	7	7	0	0	0	D	D	0	D	D	D	0	7
12:00 AM	7	0	0	0	D	D	0	0	[illegible]	D	0	7	7	7	0	0	0	D	D	0	D	D	D	0	7
12:15 AM	7	0	0	0	D	D	0	0	[illegible]	D	0	7	7	7	0	0	0	D	0	0	D	D	D	0	7
12:30 AM	7	0	0	0	D	0	0	0	[illegible]	D	0	7	7	7	0	0	0	D	0	0	D	D	D	0	7
12:45 AM	7	0	0	0	D	0	0	D	D	D	0	7	7	7	7	0	0	D	0	0	D	0	D	D	0
1:00 AM	7	7	0	0	D	0	0	D	D	D	0	7	7	7	7	0	0	0	0	0	D	0	D	D	0
1:15 AM	7	7	0	0	0	0	0	D	D	D	0	7	7	7	7	0	0	0	D	0	D	0	D	D	0
1:30 AM	7	7	0	0	0	D	0	D	D	D	0	7	7	7	7	0	0	0	D	0	D	0	D	D	0
1:45 AM	7	7	0	0	0	D	0	[illegible]	0	[illegible]	D	0	7	7	7	0	0	0	D	0	D	D	D	D	0
2:00 AM	7	7	0	0	0	D	0	[illegible]	0	[illegible]	D	0	7	7	7	0	0	0	D	0	D	D	D	D	0
2:15 AM	7	7	0	0	0	D	0	[illegible]	0	[illegible]	D	0	[illegible]	0	7	0	0	0	D	0	D	D	D	D	0
2:30 AM	7	7	0	0	0	D	0	[illegible]	0	[illegible]	D	0	[illegible]	0	7	0	0	0	D	0	D	D	D	D	0
2:45 AM	7	7	0	0	0	D	0	[illegible]	D	D	D	0	[illegible]	0	7	7	0	0	D	0	D	D	0	D	D
3:00 AM	7	7	7	0	0	0	0	[illegible]	D	D	D	0	0	0	7	7	0	0	0	0	D	D	0	D	D
3:15 AM	7	7	7	0	0	0	0	[illegible]	D	D	D	0	0	0	7	7	0	0	0	0	D	D	0	D	D
3:30 AM	7	7	7	0	0	0	0	[illegible]	D	D	D	0	0	0	7	7	0	0	0	0	D	D	0	D	D
3:45 AM	7	7	7	0	0	0	0	[illegible]	D	0	D	D	0	0	7	7	0	0	0	0	0	D	D	D	D
4:00 AM	7	7	7	0	0	0	0	[illegible]	D	0	D	D	0	0	7	7	0	0	0	0	0	D	D	D	D
4:15 AM	7	7	7	0	0	0	0	[illegible]	D	0	D	D	0	0	7	7	0	0	0	0	0	D	D	D	D
4:30 AM	7	7	7	0	0	0	0	[illegible]	D	0	D	D	0	0	7	7	0	0	0	0	0	D	D	D	D
4:45 AM	7	7	7	0	0	0	0	0	[illegible]	D	D	D	0	0	7	7	7	0	0	0	D	D	D	0	D
5:00 AM	7	7	7	7	0	0	0	0	[illegible]	D	D	D	0	0	7	7	7	0	0	0	D	D	D	0	D
5:15 AM	7	7	7	7	0	0	0	0	[illegible]	D	D	D	0	0	7	7	7	0	0	0	D	D	D	0	D
5:30 AM	0	7	7	7	0	0	0	0	[illegible]	D	D	D	0	0	7	7	7	0	0	7	D	D	D	0	D
5:45 AM	0	7	7	7	0	0	0	D	D	[illegible]	0	D	0	0	7	7	7	0	0	7	D	0	D	D	D
6:00 AM	0	7	7	7	0	0	0	D	D	[illegible]	0	D	0	0	7	7	7	0	0	7	D	0	D	D	D
6:15 AM	0	7	7	7	0	0	0	D	D	[illegible]	0	D	0	0	7	7	7	0	0	7	D	0	D	D	D
6:30 AM	0	7	7	7	0	0	7	0	D	D	0	D	0	0	7	7	7	0	0	7	0	0	D	D	D
6:45 AM	0	7	7	7	0	0	7	D	0	[illegible]	D	D	0	0	7	7	7	7	0	7	0	D	D	D	0
7:00 AM	0	7	7	7	7	0	7	D	0	[illegible]	D	D	0	0	7	7	7	7	0	7	0	D	D	D	0
7:15 AM	0	7	7	7	7	0	7	D	0	[illegible]	D	D	0	D	0	7	7	7	0	7	0	D	D	D	0
7:30 AM	D	7	7	7	7	0	7	0	0	[illegible]	D	D	0	D	0	7	7	7	0	7	0	D	D	D	0
7:45 AM	D	0	7	7	7	0	7	0	[illegible]	D	D	0	0	D	0	7	7	7	7	7	0	D	0	D	D
8:00 AM	D	0	7	7	7	0	7	0	[illegible]	D	D	0	0	D	0	7	7	7	7	7	0	D	0	D	D
8:15 AM	D	0	7	7	7	0	7	0	[illegible]	D	D	0	0	D	0	7	7	7	7	7	0	D	0	D	D
8:30 AM	D	0	7	7	7	0	7	0	[illegible]	D	D	0	0	D	0	7	7	7	7	7	0	0	0	D	D
8:45 AM	D	0	7	7	7	7	7	0	[illegible]	0	D	D	0	D	0	7	7	7	7	7	0	0	D	D	D
9:00 AM	D	0	7	7	7	7	7	0	[illegible]	0	D	D	0	D	0	7	7	7	7	7	0	0	D	D	D
9:15 AM	D	0	7	7	7	7	7	0	[illegible]	0	D	D	0	D	D	7	7	7	7	7	0	0	D	D	D
9:30 AM	D	D	0	7	7	7	7	0	0	0	D	D	0	D	D	0	7	7	7	7	0	0	D	D	D
9:45 AM	D	D	0	7	7	7	7	0	0	[illegible]	D	D	0	D	D	0	7	7	7	7	0	0	D	0	D
10:00 AM	D	D	0	7	7	7	7	0	0	[illegible]	D	D	0	D	D	0	7	7	7	7	0	0	D	0	D
10:15 AM	D	D	0	7	7	7	7	0	0	[illegible]	D	D	0	D	D	0	7	7	7	7	0	0	D	0	D
10:30 AM	D	D	0	7	7	7	7	0	0	[illegible]	D	D	0	D	D	0	7	7	7	7	0	0	0	0	D
10:45 AM	D	D	0	7	7	7	7	0	0	[illegible]	0	D	0	D	D	0	7	7	7	7	0	0	0	D	D
11:00 AM	D	D	0	7	7	7	7	0	0	[illegible]	0	D	0	D	D	0	7	7	7	7	0	0	0	D	D
11:15 AM	D	D	0	7	7	7	7	0	0	[illegible]	0	D	0	0	D	D	0	7	7	7	0	0	0	D	D
11:30 AM	0	D	D	7	7	7	7	0	0	0	0	D	0	0	D	D	0	7	7	7	0	0	0	D	D
11:45 AM	0	D	D	0	7	7	7	0	0	0	D	D	0	0	D	D	0	7	7	7	0	0	0	D	0
12:00 PM	0	D	D	0	7	7	7	0	0	0	D	D	0	0	D	D	0	7	7	7	0	0	0	D	0
12:15 PM	0	D	D	0	7	7	7	0	0	0	D	D	0	D	D	D	0	7	7	7	7	0	0	D	0
12:30 PM	D	D	D	0	7	7	7	0	0	0	D	D	0	D	D	D	0	7	7	7	7	0	0	0	0
12:45 PM	D	D	D	0	7	7	7	0	0	0	D	0	0	D	D	D	0	7	7	7	7	0	0	0	D
1:00 PM	D	D	D	0	7	7	7	0	0	0	D	0	0	D	D	D	0	7	7	7	7	0	0	0	D
1:15 PM	D	D	D	0	7	7	7	7	0	0	D	0	0	D	0	D	D	7	7	7	7	0	0	0	D
1:30 PM	D	0	D	D	0	7	7	7	0	0	0	0	0	D	0	D	D	0	7	7	7	0	0	0	D
1:45 PM	D	0	D	D	0	7	7	7	0	0	0	D	0	D	0	D	D	0	7	0	7	0	0	0	D
2:00 PM	D	0	D	D	0	7	7	7	0	0	0	D	0	D	0	D	D	0	7	0	7	0	0	0	D
2:15 PM	D	0	D	D	0	7	7	7	0	0	0	D	0	D	D	D	D	0	7	0	7	7	0	0	D
2:30 PM	D	D	D	D	0	7	7	7	0	0	0	D	0	D	D	D	D	0	0	0	7	7	0	0	0
2:45 PM	D	D	D	D	0	7	0	[illegible]	0	0	0	D	0	D	D	D	D	0	0	0	7	7	0	0	0
3:00 PM	D	D	D	D	0	7	0	[illegible]	0	0	0	D	0	D	D	D	D	0	0	0	7	7	0	0	0
3:15 PM	D	D	D	D	0	7	0	[illegible]	7	0	0	D	0	D	D	0	D	D	0	0	7	7	0	0	0
3:30 PM	D	D	0	D	D	0	0	[illegible]	7	0	0	0	0	D	D	0	D	D	0	0	7	7	0	0	0
3:45 PM	D	D	0	D	D	0	0	[illegible]	7	0	0	0	0	D	D	0	D	D	0	0	7	7	0	0	0
4:00 PM	D	D	0	D	D	0	0	[illegible]	7	0	0	0	0	D	D	0	D	D	0	0	7	7	0	0	0
4:15 PM	D	D	0	D	D	0	0	[illegible]	7	0	0	0	0	0	D	D	D	D	0	0	7	7	7	0	0
4:30 PM	0	D	D	D	D	0	0	[illegible]	7	0	0	0	0	0	D	D	D	D	0	0	7	7	7	0	0
4:45 PM	0	D	D	D	D	0	0	[illegible]	7	0	0	0	0	0	D	D	D	D	0	0	7	7	7	0	0
5:00 PM	0	D	D	D	D	0	0	[illegible]	7	0	0	0	0	0	D	D	D	D	0	0	7	7	7	0	0
5:15 PM	0	D	D	D	D	0	0	[illegible]	[illegible]	[illegible]	0	0	0	D	D	D	0	D	0	0	7	7	7	0	0
5:30 PM	D	D	D	0	D	0	0	[illegible]	[illegible]	[illegible]	0	0	0	D	D	D	0	D	0	0	7	7	7	0	0
5:45 PM	D	D	D	0	D	0	0	[illegible]	[illegible]	[illegible]	0	0	0	D	D	D	0	D	0	0	7	7	7	0	0
6:00 PM	D	D	D	0	D	0	0	[illegible]	[illegible]	[illegible]	0	0	7	D	D	D	0	D	0	0	7	7	7	0	0
6:15 PM	D	D	D	0	D	0	0	[illegible]	[illegible]	[illegible]	0	0	7	D	0	D	D	D	0	0	7	7	7	7	0
6:30 PM	D	0	D	D	D	0	0	[illegible]	[illegible]	[illegible]	0	0	7	D	0	D	D	D	0	0	7	7	7	7	0
6:45 PM	D	0	D	D	D	0	0	[illegible]	[illegible]	[illegible]	0	0	7	D	0	D	D	D	0	D	0	7	7	7	0
7:00 PM	D	0	D	D	D	0	0	[illegible]	[illegible]	[illegible]	0	0	[illegible]	0	0	D	D	D	0	D	0	7	7	7	0
7:15 PM	0	0	D	D	D	0	0	[illegible]	7	7	7	0	[illegible]	0	D	D	D	0	0	D	0	7	7	7	7
7:30 PM	0	D	D	D	0	0	0	[illegible]	7	7	7	0	[illegible]	0	D	D	D	0	0	D	0	7	7	7	7
7:45 PM	0	D	D	D	0	0	D	0	[illegible]	7	7	0	[illegible]	0	D	D	D	0	0	D	0	7	7	7	7
8:00 PM	0	D	D	D	0	0	D	0	[illegible]	7	7	0	[illegible]	0	D	D	D	0	0	D	0	7	7	7	7
8:15 PM	0	D	D	D	0	0	D	0	[illegible]	7	7	7	7	0	D	0	D	D	0	D	0	7	7	7	7
8:30 PM	0	D	0	D	D	0	D	0	[illegible]	7	7	7	7	0	D	0	D	D	0	D	0	7	7	7	7
8:45 PM	0	D	0	D	D	0	D	0	[illegible]	7	7	7	7	0	D	0	D	D	0	D	D	0	7	7	7
9:00 PM	0	D	0	D	D	0	D	0	[illegible]	7	7	7	7	0	0	0	D	D	0	D	D	0	7	7	7
9:15 PM	0	0	0	D	D	0	D	0	[illegible]	7	7	7	7	0	0	D	D	D	0	D	D	0	7	7	7
9:30 PM	0	0	D	D	D	0	D	0	[illegible]	7	7	7	7	0	0	D	D	D	0	D	D	0	7	7	7
9:45 PM	0	0	D	D	D	0	D	D	0	[illegible]	7	7	7	0	0	D	D	D	0	D	D	0	7	7	7

Source: ICF Consulting Analysis

Exhibit F-7 provides the average hours worked and slept in 8 days or 24 hours at this stage in the development of schedules.

Exhibit F-7
Modeled Hours Worked and Slept

Scenario	Modeled Avg Hrs Work / 7 Days*	Modeled Avg Hrs Work / 24-Hrs	Modeled Avg Hrs Sleep (Work Days Only)	Modeled Avg Hrs Sleep (8 Day Total)
Status Quo	63.4	12.4	6.1	7.1
Current, Fully Enforced	55.2	12.2	6.2	7.1
PATT	51.5	10.8	6.4	7.4
FMCSA	60.4	11.7	6.2	7.2
ATA	61.4	12.0	6.2	7.0

Source: ICF analysis
*Figures calculated first over eight days and then scaled down to seven days.

F.4 Spreadsheet Crash Increment Calculations

After generating each rolling and non-rolling schedule modeled for each driver proportion cell, we calculate the crash risk increments by feeding the schedules into the Sleep/Performance spreadsheet. Results are displayed in Exhibits F-8 through F-10.

Exhibit F-8
Model Crash Increment Results, Stable Work/Sleep Pattern

Hours Work / Day	Days Work / Week				
	3	5	6	7	8
9	10%	14%	16%	18%	20%
11	13%	18%	20%	23%	26%
13	14%	21%	24%	28%	32%
15	23%	34%	41%	48%	57%

Percentages rounded for presentational purposes.
Source: ICF Analysis, RoutePro Simulations

Exhibit F-9
Model Crash Increment Results, Daily Schedule Rolls Backward

Hours Work / Day	Days Work / Week				
	3	5	6	7	8
9	30%	35%	35%	38%	42%
11	34%	42%	45%	51%	57%
13	37%	47%	53%	63%	76%
15	47%	63%	75%	96%	115%

Percentages rounded for presentational purposes.
Source: ICF Analysis, RoutePro Simulations

Exhibit F-10
Model Crash Increment Results, ATA Schedule (Rolls Forward)

	Days Work / Week				
Hours/Day	**3**	**5**	**6***	**7**	**8**
9	Same as Roll Backward or No Roll, as Relevant				
11	Same as Roll Backward or No Roll, as Relevant				
Regional, 13					
No Roll	Same as no roll for other options	--	24%	--	--
Soft Roll	14%	--	28%	--	--
Hard Roll	--	--	71%	--	--
Long-Haul, 13					
No Roll	12%	--	21%	--	--
Soft Roll	14%	--	33%	--	--
Hard Roll	--	--	74%	--	--
Regional, 15					
No Roll	Same as no roll for other options	--	37%	--	--
Soft Roll	21%	--	41%	--	--
Hard Roll	--	--	103%	--	--
Long-Haul, 15					
No Roll	20%	--	34%	--	--
Soft Roll	20%	--	45%	--	--
Hard Roll	--	--	105%	--	--

*5.7 days in 8 days for 13 hour / day schedule;
5.3 days in 8 days for 15 hour / day schedule.
"Hard Roll" ["Soft Roll"] indicate work schedules of >=90 [<90] hours/week that do not [do] allow drivers to reset their sleep time. (See text for further explanation.)

Percentages rounded for presentational purposes.
Source: ICF Analysis, RoutePro Simulations

The interpretation of the crash increment in the first figure, Exhibit F-8 is that the Sleep/Performance spreadsheet indicates that drivers with stable work schedules who work nine hours a day three days a week under ATA have a 10 percent higher crash increment than in the baseline in which drivers receive 8.25 hours of sleep nightly. In contrast, the spreadsheet indicates that those with stable work schedules who are on-duty 15 hours a day eight days per work week have a 57 percent higher crash increment than the baseline. The crash increments are higher for those with schedules that roll in Exhibit F-9. Drivers with work schedules that roll backwards two hours per cycle and work nine hours a day three days a week have a 30 percent higher crash increment than in the baseline and those on-duty 15 hours a day eight days per work week have a 115 percent higher crash increment than the baseline.

The table in Exhibit F-10 showing model crash increment results for ATA schedules differs in presentation due to the adjustments discussed in F-3. For those drivers who work on average nine or 11 hours per day, there is no difference between the crash increments for drivers under ATA versus under the other options. This is true as well for regional drivers who work three days a week and whose schedules do not roll. As discussed previously, those who work 13 or 15 hours per daily cycle are modeled as working only either three or about six days per week. For a driver from a regional carrier who works 13 hours per daily cycle three days a week and then lets his sleep schedule reset to his circadian rhythm,[43] his crash increment is 14 percent above baseline – identical to that found in Exhibit F-8 when schedules do not roll and below the increment of 37 percent for schedules that roll backward. The schedules that roll forward "softly" have lower crash increments than those rolling backward because a schedule that rolls forward a few hours off of the ideal pushes driving time slightly later in the day, when the second, lower circadian peak rises. Because the sleep-work schedules reset after three days, they never continue rotating to sub-optimal sleep and work times. Similarly, for regional drivers working 13 hours six days a week whose schedules include a "soft" roll, the crash increment is 28 percent, just 4 percent higher than when the schedule does not roll.

In contrast, a regional driver working the same number of hours and days but who has a "hard" rolling schedule that does not let his sleep cycle reset has a crash increment 71 percent above baseline. Long-haul drivers working 13 hours per work cycle have only modestly different crash increments from regional drivers. Drivers who work 15 hours a day six days per eight day work week and have schedules that have a "soft" roll forward have lower crash increments than those whose schedules roll backwards under other proposals. The opposite is true for those with schedules that have a "hard" roll forward. The schedules that have a "hard" roll forward (driving as soon as the mandatory off-duty break is completed) have higher crash increments than those rolling backward because these schedules never allow a driver to reset his sleep period to his circadian rhythms. Instead, the schedules continue rolling through sub-optimal time periods for driving and sleeping.

F.5 WEIGHTING CRASH INCREMENTS, PRODUCTIVITY AND PROPORTION FATIGUE-RELATED

The crash risk increments calculated in section F-4 are multiplied by the percentage of drivers found in each cell in the driver schedule proportion matrix (such as that shown for the status quo in Exhibit F-2). This calculation is made for each proposal option for rolling and non-rolling schedules. The resulting value is subtracted from the baseline crash increment under schedules with eight hours of regular sleep for an interim crash increment score for each scenario – current compliance status quo, current rule with full compliance, PATT, ATA, and FMCSA.

We adjust these interim crash increments for the differences in productivity found through these calculations from the productivity found in generating the cost estimates. Because of a number of modeling simplifications, we expect the average number of hours per week of drivers modeled in this process to vary slightly from that found in the cost analysis. We scale crash risk estimates up or down using the ratio of productivity found in the cost analysis to that found in the crash risk analysis. Due to other adjustments for productivity, only the current HOS rules, fully enforced required an adjustment for productivity.

We then multiply the results by the proportion of truck crashes in which fatigue may have played a role. As discussed in section 8.2, the fatigue-susceptible truck crash proportion is estimated to be 30.5 percent of all truck crashes. Only truck crashes in which truck driver fatigue is

[43] A "hard" rolling schedule is not possible for drivers working three days a week.

considered to have potentially played a role are included in this proportion. The productivity adjustments and the modeled fatigue-related crash increments calculated across all cells in a driver proportion matrix are shown in Exhibit F-11.

Exhibit F-11
Modeled Crash Increment & Productivity Adjustment

Scenario	Modeled Crash Increment vs Baseline	Productivity Adjustment Factor
Status Quo	11.5%	0.0%
Current, Fully Enforced	8.4%	5.7%
PATT	6.0%	0.0%
FMCSA	7.0%	0.0%
ATA	10.3%	0.0%

Source: ICF analysis

The final step discussed in this section is to convert the modeled crash increment into the percentage of crashes that are related to fatigue. That is, we start with the amount of crashes for each option that occur only due to fatigue (modeled fatigue increment) and calculate the percentage of all crashes, both fatigue-related and non fatigue-related, that are caused by fatigue (fatigue-related percentage).[44] The percentage of fatigue-related crashes is found by dividing the modeled crash increments in the first column of Exhibit F-11, Scheduling Results, by the total number of crashes including those that both are and are not fatigue-related. The calculation for fatigue-related crashes is simply the modeled crash increment (calculated relative to baseline) divided by 100 percent plus the raw crash increment (raw increment)/(1+raw increment). For the status quo scenario, this is 11.5%/(100%+11.5%) = 10.3%, as shown in Exhibit F-12.

Exhibit F-12
Crash Increment and Fatigue-Related Crashes

Scenario	Status Quo	Current, Fully Enforced	PATT	ATA	FMCSA
Raw Crash Increment vs Baseline	11.5%	8.4%	6.0%	10.3%	7.0%
Fatigue-Related Crashes	10.3%	7.8%	5.7%	9.4%	6.5%

Source: ICF analysis

[44] As an example for clarification, suppose for the status quo that the fatigue increment were 100 percent. That is, in this hypothetical example, fatigue causes as many crashes in the status quo as would occur without driving under fatigued conditions. Fatigue does not cause 100 percent of actual crashes – only 50 percent. This percentage is calculated by dividing 100 percent by 100 percent + 100 percent, or 100 percent / 200 percent = 50 percent.

APPENDIX G.
PROCEDURE FOR ESTIMATING INCREMENTAL RELATIVE CRASH RISK: THE SLEEP PERFORMANCE SPREADSHEET

The incremental relative crash risk related to the options is estimated by assessing multi-day driver schedules of work and sleep using a computer program based very closely on the Walter Reed Sleep Performance model (WRAIR-SPM). This program is implemented in a spreadsheet, and referred to as the Sleep Performance (SP) spreadsheet. This appendix describes the use of the spreadsheet and the calculations it performs.

G.1 USE OF DRIVER SCHEDULES

Multiple schedules of work, driving, and sleep are assessed for each option, and the crash risk is computed for each one and compared to the risks under a baseline schedule without fatigue. For each schedule, then, the incremental crash risk is found, compared to a non-fatigued baseline, thereby showing the increase in crash risk attributable to the fatigue inherent in that schedule.

The overall risk increment associated with a particular HOS rule option is estimated by taking a weighted average of the incremental risks across various schedules. The incremental crash risks under all of the schedules are weighted according to our estimates of their prevalence under a given option. In an option that allows more time off, for example, the schedules with more time off for drivers – and thus more sleep – are given greater weight. In an option that promotes rapidly shifting work hours, the schedules with greater variability in the times of work and rest are weighted more heavily.

One key component of the analysis, then, is the establishment and weighting of the schedules. (For greater detail about the different schedule types and weighted, see Chapter 8.6 and Appendix F.) The outcome of this procedure is a set of schedules for 23-day periods, in which each 15 minute period is coded as sleeping, driving, or awake but not driving.[45] The length of the schedule is chosen to be long enough to cover multiple periods of work and recovery, so that cumulative effects of fatigue could be assessed, while being short enough to be tractable. The analytical period of 15 minutes is chosen to be short enough to measure the effects of small changes in daily sleep.

Equally important is the estimation of the incremental crash risk for a given schedule. That procedure is described in the following section.

G.2 CALCULATION OF INCREMENTAL CRASH RISK

The relative crash risk for a driver on a given schedule is calculated over a 23-day span by tracking the driver's alertness over time and estimating the effect of the level of alertness on the relative likelihood of crashing for each 15 minute period of driving. Alertness is measured using the driver's predicted score on the PVT or psychomotor vigilance task, as calculated using the algorithms developed for the WRAIR-SPM.

[45] For purposes of calculating crash risk, there is no difference between coding a period as awake and working but not driving, or awake but not working. We therefore code these periods the same.

G.2.1 Scaling the PVT Scores

The WRAIR-SPM predicts PVT scores on a scale of 0 to 100, in which 100 is the level that would be attained by a typical individual with no sleep debt – which is assumed to be the case for someone who has consistently slept for eight hours per night. In calculating the PVT scores, the level of 100 is initially assigned to an artificial state of sleep saturation, in which the individual never experiences a degradation to his potential performance. Relative to this optimal condition, an individual who was awake for 16 hours out of 24 and asleep for 8 hours per night would register a score of 80: the degradation of performance due to the waking hours would be just balanced out by the restorative effects of sleep. Because an individual in this condition is not considered to suffer from sleep deprivation, the PVT score as initially calculated is rescaled by multiplying it by a factor of 1.25, which brings a score of 80 up to 100. In the material that follows, we refer to a the score before it is multiplied by 1.25 as "unscaled" and the score after it has been multiplied by 1.25 as "rescaled."

G.2.2 SP Spreadsheet Inputs

The SP spreadsheet consists of a set of equations that transform a small set of inputs into relative crash risk estimates. These inputs include the schedule data discussed above and several parameters. Six parameters are based on parameters from the WRAIR-SPM, and determine the rate at which performance (measured by the PVT) declines when an individual is awake, the rate at which it is restored by sleep, the magnitude and timing of the 24-hour "circadian" cycle, and the magnitude and timing of the 12-hour "ultradian" cycle. We have added a parameter that shifts the circadian and ultradian cycles so that they peak at a different time of day, a parameter that sets the initial unscaled PVT score, and parameter that sets the factor by which the unscaled score is increased to turn it into the rescaled score.

Other inputs include the coefficients of the regression equation that relates the rescaled PVT level to relative crash risk, and parameters for a function that adjusts the sleep inputs to take into account the effect of time of day on the quantity of sleep. Each of these parameters are discussed in more detail at the appropriate points in the sections below.

G.2.3 Steps in the Calculation of PVT Scores

The unscaled PVT score starts at a level that is a user input, generally taken to be 80, which is the level indicating a well-rested condition. From that point, the model first estimates changes to the unscaled PVT score caused by sleep or being awake, then adds circadian and ultradian effects. The PVT score is then rescaled, and used to estimate a relative crash risk for periods of driving. Finally, the average crash risk is calculated for all of the periods after the first week (the first week is left out to allow the individual's score to damp out the effects of the assumption that he or she starts out fully rested).

Effects of Sleep Starting with the initial unscaled PVT level of 80 in the first 15-minute period, the model first determines if the individual is awake or asleep, based on the schedule that was entered. If the individual is asleep, the PVT score is increased.[46] The amount of the increase depends in part on whether or the individual has just fallen asleep; if not, the increase in the PVT score is calculated as

$$\text{param\_c2/4} * (100\text{-PVT}_{-1}) * (\text{H}/100),$$

where param_c2 is the per-hour rate of sleep restoration for a totally sleep-deprived individual, PVT-1 is the previous period's PVT level, and H is an adjustment to sleep to account for the difficulty of sleeping at the wrong time of day.

The basic calculation of the effect of sleep on unscaled PVT is expressed by the first two terms: the addition to PVT will be equal to a quarter of param_c2 times the difference between 100 and the pre-existing value of PVT. Param_c2 is the hourly rate of increase in PVT for an individual who is completely sleep-deprived; because the time period used in the model is a quarter of an hour, param_2 is divided by 4. The value of param_c2 is 0.0362, which was taken directly from the WRAIR-SPM software. The restorative effects of sleep in the WRAIR-SPM are based on the concept that sleep's effects are proportional to the level of sleep deprivation, so the effects of sleep are reduced as the sleep "reservoir" fills and gets closer to 100. Thus, if the current level of PVT is equal to 80, the effects of sleep will be only (100 – 80) * param_c2/4, or a fifth as large as if PVT had been 0.

The third term in the expression multiplies the effect of sleep by a correction factor that increases or decreases the change in PVT depending on the time of day at which the sleep takes place. This term is included because the calculations of sleep quantity used to create the schedules for the drivers omitted the effect of time of day on the quantity of sleep people tend to get. Increasing the effect on PVT of a given quantity of sleep was a simple way to show what happens to PVT if sleep is taken at a time that is conducive to greater amounts of sleep. The origin and form of the equation used to simulate the effects of time of day on sleep quantities is, because of its complexity, presented separately at the end of this Appendix.

As stated, the calculation of the effects of sleep are different if the individual has just fallen asleep. The effectiveness of sleep in the first 15-minute period of sleep is reduced by a third, in line with the assumption in the WRAIR-SPM that the first five minutes of sleep have no restorative effect.

Effects of Being Awake If the individual is awake, unscaled PVT is calculated as PVT-1 + param_c1/4, where PVT-1 is the previous period's PVT score, and param_c1 is the parameter specifying the hourly rate at which PVT drops while an individual is awake. Param_c1 is specified as –0.392, and is taken directly from the WRAIR-SPM software. It is divided by four in this expression because the time period is a quarter of an hour and thus the effect of being awake is only a fourth of the hourly effect.

[46] As implemented in the spreadsheet, the increase to the PVT score is based on the sleep that took place in the previous period, to avoid problems of circular references. This small difference from the ideal calculations would make essentially no difference, because the crash risks are not assessed except when the individual is driving, which will be several time increments removed from the sleep periods.

Circadian Effects After the effects of sleep or being awake have been estimated, the unscaled PVT score is adjusted in accordance with the individual's daily cycles. These cycles are modeled as including a 24-hour cycle (the "circadian" cycle) and a 12-hour cycle (the "ultradian" cycle); together, these are referred to as "circadian" effects. In the WRAIR-SPM, they are assumed to increase or decrease the PVT score by a percentage calculated as the sum of two cosine function. The percentage adjustment is equal to

param_c3*cos((2*pi/24)*time+param_c4) + param_c5*cos((2*pi/12)*time+param_c6). The two cosine functions in this expression depend on time of day (measured in hours from 0 to 24) and four parameters, which determine the magnitudes and timing of the circadian effects.

Param_c3 determines the magnitude of the 24-hour cycle. The value of param_c3 is 6.72 in this model, meaning that the circadian peak adds 6.72 percent to the PVT score, and the circadian trough subtracts 6.72 percent. Similarly, param_c5 determines the magnitude of the 12-hour cycle; it is 2.5 in this model. Both param_c3 and param_c5 are taken directly from the Walter Reed software. Param_c4 determines the timing of the 24-hour cycle, and param_c6 does the same for the 12-hour cycle. These parameters were set at 1.136 and 1.246, respectively. These values were based on the parameters in Walter Reed software but increased by enough to shift the cycles 2.5 hours earlier. This shift moved the peak back from just after midnight to about 10 PM, and moved the trough from about 9:30 AM to about 6:00 AM. The shift in the timing of the cycles was done to bring the timing of the troughs closer to the early morning hours, and is very close to the 3-hour shift used by Walter Reed in setting up the field version of its model.

Rescaling the PVT Value After the unscaled PVT value from the previous time period has been adjusted up (if the individual is asleep) or down (if awake), and has been increased or decreased by a percentage based on the circadian effects, it is multiplied by 1.25. This transformation rescales PVT so that well-rested person would score 100.

The steps described above are repeated for each successive time increment, resulting in a series PVT values that rise and fall throughout the day depending on when the individual is asleep or awake, and what part of the circadian cycle he or she is in.

As an example, suppose it is 1:00 AM, the individual's unscaled PVT score (unadjusted for circadian effects) is 75, and he is awake. The unscaled PVT score for that period would be calculated as 75 - 0.392/4 or 74.902, times

1 + [6.72*cos((2*pi/24)*1+1.136) + 2.5*cos((2*pi/12)*1+1.246)] or 74.902 * 1.0066, which equals 75.4. If the individual stays awake for another 15 minutes, the unscaled PVT score would fall to 74.902 - 0.392/4 or 74.804, times

1 + [6.72*cos((2*pi/24)*1.25+1.136) + 2.5*cos((2*pi/12)*1.25+1.246)] – or

74.804 * 0.9991, which equals 74.74.

If the individual then fell asleep, his unscaled PVT score would rise to

74.804+(100-74.804) * 0.0362/4 * 1.14 *2/3 or 74.977, times

1 + [6.72*cos((2*pi/24)*1.5+1.136) + 2.5*cos((2*pi/12)*1.5+1.246)] – or 74.977 * 0.9917, which equals 74.356. In this calculation, the factor 1.14 is an adjustment to the sleep effect to allow for the fact that individuals are likely to sleep more if they are sleeping at night than during

the day; it is calculated as explained at the end of this appendix. The factor of 2/3 is an adjustment to the effectiveness of the 15-minute period of sleep because the first 5 minutes of the period are assumed not to have a restorative effect. If the individual continues to sleep, the unscaled PVT score would become

74.977 + (100 – 74.977) * 0.0362/4 * 1.14 or 75.235, times

1 + [6.72*cos((2*pi/24)*1.75+1.136) + 2.5*cos((2*pi/12)*1.75+1.246)] – or

75.235 * 0.984, which equals 74.068.

Exhibit G-1 shows the example PVT value calculations discussed above.

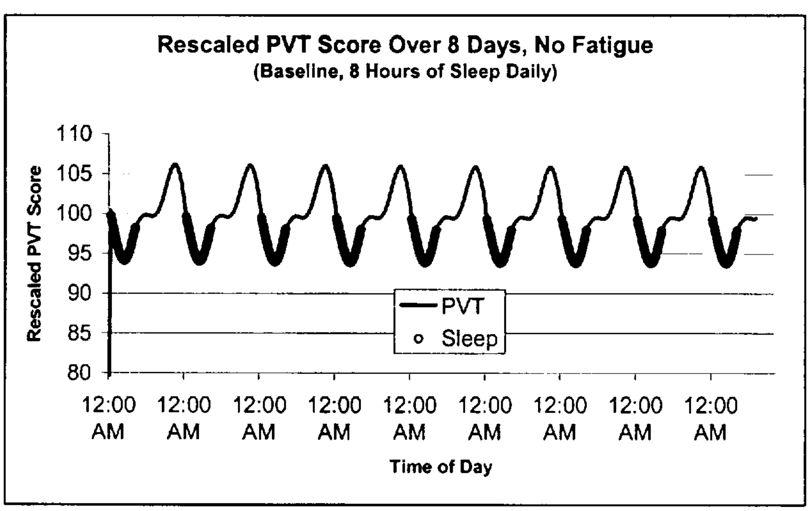
Exhibit G-1
Examples of PVT Calculations

Status	Initial Unscaled PVT without Circadian Effects	Decreased if Awake	Increase if Asleep	Final Unscaled PVT Without Circadian Effects	Circadian Adjustment	Final Unscaled PVT	Final Scaled PVT
Awake	75.0	-0.098	NA	74.902	1.0066	75.399	94.249
Awake	74.092	-0.098	NA	74.804	0.9991	74.738	93.423
Asleep	74.804	NA	0.173	74.977	0.9917	74.356	92.945
Asleep	74.977	NA	0.258	75.235	0.9845	74.068	92.585

Source: ICF calculations

The output of the SP spreadsheet is illustrated in the following graphs, which show how the rescaled PVT score varies over time for three distinct schedules. The first is a baseline schedule in which an individual obtains eight hours of sleep per night, and therefore does not suffer fatigue related to lack of sleep. Daily patterns of increasing and decreasing alertness, due to circadian effects, may be seen in the graph. Sleep is shown occurring during the lowest periods in the circadian cycle.

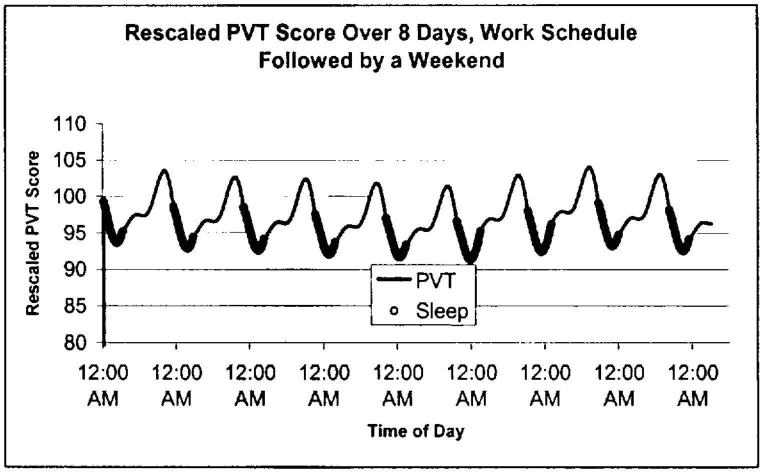
Exhibit G-2



Source: SP spreadsheet and ICF analysis.

The second graph shows how the rescaled PVT scores would be affected by a work schedule that allowed less than eight hours of sleep per night for five days, followed by a weekend in which adequate sleep was obtained. The PVT scores still vary throughout individual days, but drift downward slightly over the work week. They then recover during the weekend.

Exhibit G-3



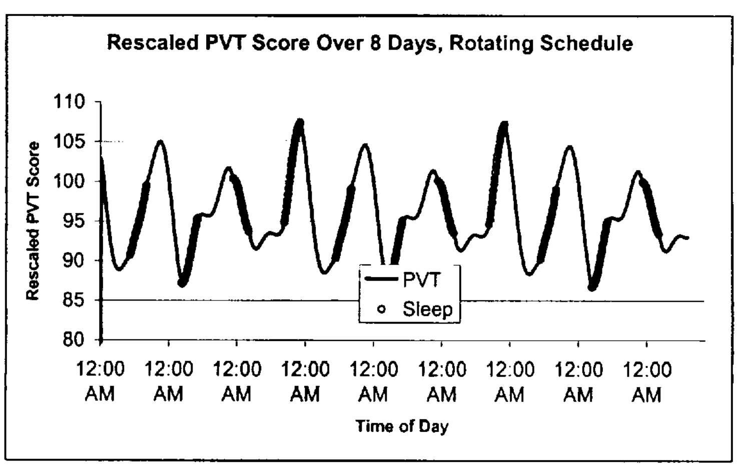
Source: SP spreadsheet and ICF analysis.

Finally, the third graph shows how the rescaled PVT scores would be affected by a rotating schedule, in which the individual had enough time off, but at times not conducive to sleep. In this graph, the periods available for driving tend to be at times when the PVT score is relatively low. In addition, PVT scores tend to drop following day-time sleep periods.

G.2.4 Estimating Relative Crash Probabilities

The relative chance of a crash if the individual is driving is calculated using a function of the final scaled PVT score, with coefficients from a regression analysis relating PVT scores to simulated crashes.

Exhibit G-4



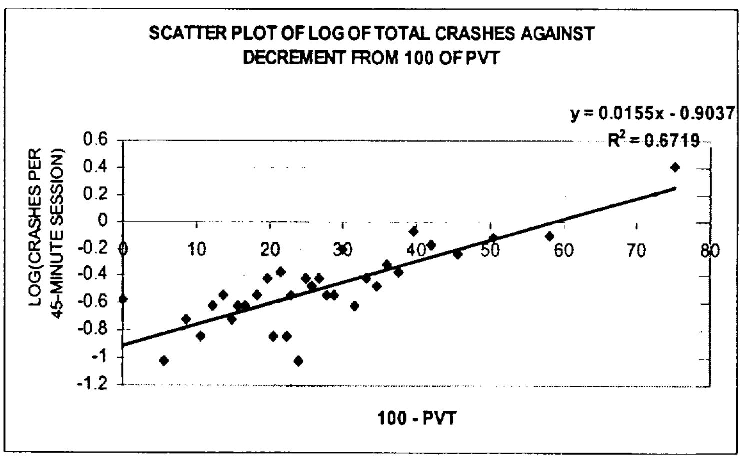
Source: SP spreadsheet and ICF analysis.

In the regression analysis, average response time data (AvgRt) for one session per day was obtained from the Walter Reed lab study. Crash data for one session per day was also obtained from the driving simulator test. For the sessions chosen, total crash incident was related to average response score. The resulting data set was sorted by average response score (in ascending order) and divided into 32 groups.

Using the grouped data, the crash variable was transformed by taking the logarithm of its observations. Corresponding average response scores were also transformed into PVT scores by taking the inverse of each score and calculating its decrement from 100.

The log of total incidents and the associated PVT scores were then used to estimate a function relating total crash incidents to PVT. The graph below presents the association between Total Crash incidents and PVT. The relationship is both strong and apparently linear, indicating that each decrease in PVT results in approximately the same percentage increase in crash risk, relative to a baseline without fatigue.

Exhibit G-5



Source: Walter Reed lab study and ICF analysis.

The results of this analysis are used to calculate the relationship between changes in PVT scores on crashes. Rather than calculating the actual probability of a crash, the spreadsheet calculates the incremental crash risk relative to the risk for a rescaled PVT score of 100 (i.e., not sleep deprived, and with a neutral circadian effect). In the graph above, the crash risk for an individual with a rescaled PVT score below 100 could be compared to the crash risk for a fully rested individual by finding the difference between the PVT score and 100, finding the corresponding point along the horizontal axis, and reading off the graph the predicted log of crashes per 45-minute driving simulation. This crash rate could then be compared to the very low crash risk for a fully rested driver by noting where the linear function crossed the vertical axis at the left-hand side of the graph.

In the spreadsheet, this comparison is made using the PVT score and the coefficients of the linear relationship shown on the graph. The crash risk relative to a fully rested driver is calculated as

$$[10^{((100\text{-PVT})*0.0155\text{-}0.9037)}/10^{-0.907}] - 1,$$

where 100-PVT is the current difference between the PVT score and 100 (i.e., a measure of fatigue), 0.0155 is the slope of a regression line relating the log of (100-PVT) to the log of the relative risk of simulated crashes in the Walter Reed laboratory study, -0.9037 is the intercept of that function (i.e., the log of simulated crash risks for drivers without fatigue), and -0.907 is a close approximation to that intercept.[47] An estimate of the increase in relative crash risk caused by fatigue is found by raising 10 to the power of the logs of the crash risks with and without fatigue, finding the ratio of two risks with and without fatigue, and subtracting 1. Note that, as described in Chapter 8, these estimates of relative crash risk are not used directly, but are adjusted so that, when realistic driver schedules are used, they yield the same fatigue-related crash increment that was calculated using real-world data.

Following the example presented above, and assuming the individual was driving for the first of the 15-minute periods described above,[48] the relative crash risk would be calculated as follows: $10^{((100-94.249)*0.0155-0.9037)} / 10^{-0.907} - 1$ or $10^{-0.0123} / 10^{-0.907} - 1$, or 23.7%. Thus, the driver with the unscaled PVT score of 75.344 instead of an ideal 80 would be 23.7% more likely to have a crash, and this increase would be attributable to fatigue. This increase should be interpreted as the increase that would be expected in crashes attributable to the actions of the truck driver, which is only a fraction of all crashes. For this analysis, we have estimated that the fraction of crashes involving trucks that were attributable to the truck driver (as opposed to weather or other drivers) is 30.5 percent (as discussed in Section 8.2). Under the assumption that truck driver fatigue would affect largely those crashes that were attributable to the actions of the truck driver, the relative increase in crashes of 23.7 percent calculated for this example would be multiplied by 30.5 percent to yield an increase in all crashes of 7.23 percent. This value is the estimated increase in crash risk caused by fatigue for the driver in the example.

In using the SP spreadsheet, similar calculations would be made for every 15-minute time period for a 23-day span, and the average increase in crash risk relative to a fully rested driver would be found for all driving periods, excluding the first week as discussed above. Note that, as described in Chapter 8, these estimates of relative crash risk are not used directly but are adjusted so that, when driver schedules that reflect the current distribution of real-world driver schedules are input, they yield the same fatigue-related crash increment that was calculated using real-world crash data. In other words, if for a realistic set of driver schedules, the SP spreadsheet predicts a 10 percent increase in crashes relative to fully rested drivers, and the estimate of the percentage of crashes caused by fatigue based on real-world crash data is 11 percent, then all of the fatigue-related crash estimates from the SP spreadsheet would be multiplied by 11/10 or 1.1. This adjustment ensures that, for current conditions, the calibrated SP spreadsheet yields a realistic value for the percentage of crashes caused by fatigue, while preserving the relative effects of different options on fatigue-related crashes. For example, if the SP spreadsheet predicted that a given option could cut the uncalibrated estimate of fatigue-related crashes from 10 percent to 5 percent, the results after calibrating it to real-world data would indicate a reduction from 11 percent to 5.5 percent – i.e., the same reduction of 50 percent from the status quo.

[47] The use of this approximation causes all of the of estimated crash increments to be overestimated by a factor of 1.0076; this small inaccuracy was corrected for at a later stage of the analysis.

[48] There is no crash risk if the individual is not driving; thus, unless the schedule indicates the individual is driving for a particular 15-minute period, no estimate of relative crash risk is made.

G.3 Estimation of a Function Relating Time of Day to Hours of Sleep

In this section, we describe the development of a function describing the relationship between the time of day that sleep occurs and the amount of sleep obtained. Since sleep patterns are affected by cyclical circadian rhythms, a cyclical function should be used to describe the relationship between the time when sleep occurs and the hours of sleep that one gets. Modeling sleep using the cosine function gives a cyclical pattern, and by using multiple cosine functions to model the data, one can account for the 24-hour circadian cycle, the 12-hour ultradian cycle, and the phase shifts of these two cycles.

Data for the regression analysis was taken from the DFACS survey (described in Appendix B). Observations reported in the survey from responses to the questions "When did you begin your last main sleep?," "How long did you rest?," When did you begin your main sleep the time before last?," and "How long did you rest then?" were used to set up the regression.

The data set was first cleaned so that it was in a useable form without outliers. Responses that were not coded AM or PM were eliminated from the data set. Outliers with less than 1 hour of sleep were rounded up to two hours. Outliers with more than 12 hours of sleep were rounded down to 12 hours except for cases where the hours of sleep were very large (> 15 hours), in which case these observations were eliminated from the dataset. After the data was cleaned, the time and hours of sleep observations from the two periods were combined to form one data set.

The data for the time of day individuals began their main sleep was used to predict the amount of sleep an individual would get. The data on the time of sleep was transformed to convert them into values that represented the midpoint of the time that main sleep occurred. This transformation was made to more accurately show when individuals were asleep. The time of day was converted into radians by dividing the hours of the day (0-24) by 24 and then multiplying by 2*pi. This data set, along with the hours of sleep, was then regressed on four different cosine functions. Each cycle (the 24-hour circadian and the 12-hour ultradian) was modeled as the sum of two cosine functions with different the same period but different phases to allow for the phase information contained in the data. The 24-hour cycle was modeled by COS(X) and COS(X-2/24*2*pi), and the 12-hour cycle was modeled with the functions COS(2X) and COS(2X-4/12*2*pi)), where X is the time of day when sleep occurred, in radians. The data on the length of sleep was regressed against these functions using the regression function in Excel, yielding coefficients for each of the four cosine functions. Using the coefficients from the regression equation yielded predicted quantities of sleep as a function of time of day.

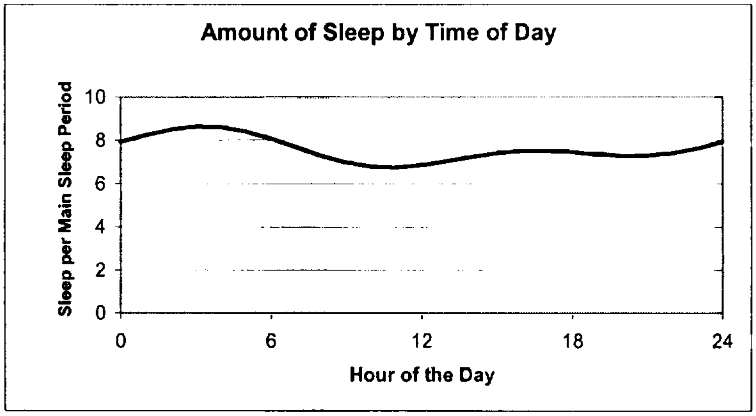
The equation that resulted, shown below, implies that individuals tend to sleep more if the period of sleep is centered around the early morning hours, and less when sleep is attempted during the late morning and afternoon. This pattern mirrors the typical individual's natural circadian rhythm.

$$\text{Sleep} = 7.58 \underset{(-0.75)}{-0.0205} * \cos(X) \underset{(2.68)}{+0.641} * \cos(X - 2/24 * 2 * \pi)$$

$$\underset{(0.5)}{+0.067} * \cos(2*X) \underset{(3.88)}{+0.506} * \cos(2*X - 4/12*2*\pi)$$

$n = 970,\ R2 = 0.067$

Exhibit G-6



Source: ICF analysis.

The explanatory power of the equation is low, indicating that many factors other than time of day affect sleep, but the coefficients on two of the cosine functions are significant.

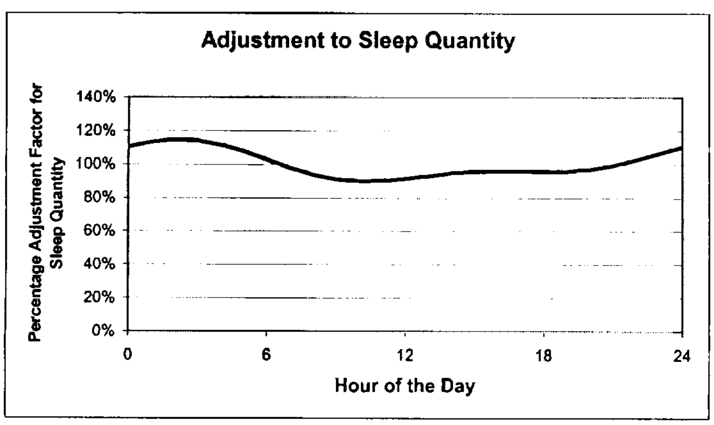
The graph displays the resulting function, which reaches a primary peak in the early morning hours, a trough at midmorning, and a secondary peak in the late afternoon. The graph relates amount of sleep in the main sleep period to the time at which the midpoint of the sleep occurs.

In implementing this pattern in the analysis, a slightly different form was used for compatibility with the modeling of circadian rhythms. Predicted sleep for a 24-hour period was multiplied by a factor equal to

$$1-(0.1008*\cos(X-3.5)-0.04875*\cos(2*X-1.4)$$

This function, shown below, was selected to have the same general shape as the function shown above, with the same peak-to-trough ratio of 1.27, a smaller secondary peak, and the main trough in the late morning. It differs in that its phases are slightly earlier, and its secondary peak is less pronounced. As with the previous graph, sleep is related to the time of the midpoint of the sleep period.

Exhibit G-7



Source: ICF analysis.

APPENDIX H. METHODOLOGY FOR ESTIMATING IMPACTS ON CARRIERS, INCLUDING SMALL CARRIERS

ICF estimated the impact on the net income of carriers due to the HOS Options using a pro forma modeling approach. This appendix provides detailed formulations of the pro forma models and assumptions used to analyze carriers in each size category. This discussion is followed by a description of the data used in the analysis. The policy variables underlying this analysis are provided in Exhibit H-1 by Option.

Exhibit H-1
Policy Variable Values by HOS Option Used in Chapter 10

POLICY VARIABLE	PATT OPTION	ATA OPTION	FMCSA OPTION
Change in Productivity*	-4.00%	+5.30%	+3.90%
Change in Salary Per Driver: Existing*	-$1,302	+$1,506	+$1,030
Change in Industry Revenues**	+0.22%	-0.34%	-0.50%
Change in # of Drivers (Short + Long-Haul)***	175,500	-85,500	-27,000[#]

* Existing drivers (long-haul)
** The industry revenue calculation is affected by the short-haul-related costs
*** National (short and long-haul) total since drivers are assumed to come from a single labor pool in determining the labor supply elasticity impact on wages
[#]The final FMCSA Option selected resulted in the need for 21,000 fewer drivers compared to full compliance, i.e., -48,000 total drivers in the U.S.; the analysis in Chapter 10 was not re-run at this point in time to reflect this change as it did not affect the results as presented (approximately a +0.03% impact on net income of firms)

These variables are the key drivers of the cost and revenue functions in each of the pro forma models, affecting firms as follows:

❑ Change in Productivity: Firms will either increase or decrease the number of drivers and associated equipment in response to a decrease or increase in productivity, respectively

- *Change in Number of Drivers* – Drivers are assumed to be available in step-wise fashion, i.e., only full-time drivers are hired or laid off

- *Decrease in Productivity* – To the extent that the incremental number of drivers needed is not an integer, the firm can either forgo the business associated with the remainder or add an additional driver with excess capacity (business remains unchanged), whichever is more profitable

- *Increase in Productivity* – To the extent that the incremental number of drivers needed is not an integer, the firm can either forgo the business associated with the remainder from laying off a driver or maintain current staffing levels with excess capacity (business remains unchanged), whichever is more profitable

- *Single-Tractor Owner/Operators*: Owner/operators are a special case and must always forgo business in response to lower productivity; these firms are assumed to be able to increase revenues in response to higher productivity, at least in the long-term

- Change in Salary Per Driver (Existing): Firms will pay the remaining/existing drivers more or less in response to a decrease or increase in productivity, respectively, as firms adjust their labor count to accommodate the change in productivity; this impact is separate from the change in wage rate associated with changes in the supply of drivers in the job market

  - Single-Tractor Owner/Operators: Owner/operators firm net income is the net revenue after expenses

  - Small Firms: Small firms that do not lay off any employees in response to the HOS option (ATA and FMCSA) because of their small size and profit-maximizing employment choices will not have to pay existing staff any differently since no driver's VMT will change

  - Larger Firms: Wages for existing driver will change in response to either lower productivity (assumed to be driving less and made up for with new staff or forgone business) or increased productivity leading to the addition of one or more new drivers

- Change in Industry Revenues: The direct impact on the costs to the trucking sector will be passed along to consumers under the assumption of constant demand in the form of uniformly higher or lower revenues to all trucking companies to cover the higher or lower costs associated with a decrease or increase in productivity, respectively

- Change in Short and Long Haul Drivers (Nationally): The percentage change in the demand for all drivers at the national level will have an impact on driver wages due to the elasticity of labor supply that occurs whether or not the firm hires or lays off any drivers (except owner/operator firms)

Exhibit H-2 summarizes the general structure of the pro forma models developed for the analysis.

Exhibit H-2
Overview of Pro Forma Model Structures Used in Chapter 10

#	LINE ITEM	CALC	EXPLANATION
1	Operating Revenues		Current Revenues adjusted for the Change in Industry Revenues and the change in business caused by the step-function associated with either hiring or laying off whole driver FTEs (vs. partial FTEs)
2	Operating Costs	(3) + (4)	Sum of operating expenditures
3	Equipment		Existing depreciation expense plus the net change in depreciation expense from the Change in Investment
4	Direct		Current operating expense less the change in expenditures associated with new drivers and changes in VMT, including new driver wages, current driver wages, supervisory wages, maintenance, insurance, recruiting, fuel, parking lot maintenance, and new licenses/fees

#	LINE ITEM	CALC	EXPLANATION
5	EBIT	(1) – (2)	Earnings Before Interest & Taxes
6	Interest Expense		Current interest expense plus the interest on the Change in Investment financed by debt based on the debt ratio of the firm
7	EBT	(5) – (6)	Earnings Before Taxes
8	Taxes	(7) * Tax_Rate	Aggregate corporate income taxes payable on the CHANGE in EBIT plus existing taxes
9	Net Income	(7) – (8)	Net Income after taxes; represents profit to shareholder equity stake in the firm
10	Change in Investment		Change in the investment in tractors, trailers, and parking required to comply with HOS Option net of first-year depreciation expense; Note: The change in the need for equipment for the direct change in employees offset by the corresponding change in VMT of existing fleet

SINGLE-TRACTOR OWNER/OPERATOR PRO FORMA MODEL DOCUMENTATION

The pro forma model for a typical owner/operator is based on a set of standard input assumptions and the cost functions developed in Chapter 6. Exhibit H-3 provides a line-by-line summary of the model and assumptions used.

GENERAL PRO FORMA MODEL DOCUMENTATION

The pro forma model for all other size categories is based on a set of standard input assumptions and the cost functions developed in Chapter 6, in association with firm-specific data described below. Exhibit H-4 provides a summary of the model parameters and assumptions used in the model. Exhibit H-5 details the pro forma model calculations line-by-line. Note that the pro forma model lays out additional firm information, such as the full balance sheet, estimated cash flow, and firm financial ratios.

INDUSTRY AND FIRM-SPECIFIC DATA SOURCES

The study considered two industry-specific data sources in developing the firm-level data inputs to the general pro forma model. TTS Blue Book financial data was used as the basis for determining the impact of the change in hours of service regulations on a variety of firm sizes. However, the Blue Book data only includes firms with revenues greater than $3 million per year (approximately 20 tractors). For firm sizes less than this, data from the Risk Management Association (RMA) were used for firms with $0 to 1 million (assumed to represent firms with 2-9 tractors) and $1 to $3 million (assumed to represent firms with 10-19 tractors).

The TTS Blue Book data were segmented into four size classes based on the number of trucks in the firm, starting with firms having 20 tractors. The size classes were selected to be consistent with the definition of a small business in the trucking sector ($21.5 million in revenues, or approximately 145 tractors based on the sample median value of $145,000 in annual revenues earned per tractor).

Exhibit H-3
Owner/Operator Pro Forma Model Parameters, Assumptions, and Equations

#	Variable	Name	Units	Base Value	Source/Calc.	Explanation
1	**Revenues**	**Rev_One**	**Dollars**	**$125,000**	(2) * (3) * (4) * (1 + (5)) * (1 + (6))	Miles driven per year (MPY_One) times the share of non-empty miles (Empty_Ratio) times the expected revenues per mile (Rate_One) adjusted for the HOS Option Impact on the change in industry costs on revenues (1 + Policy_Rate) and on productivity (1 + Policy_Derate)
2	Miles Per Year	MPY_One	Miles	120,000	ICF	Miles driven per year
3	Empty Ratio	Empty_Ratio	Share	83.33%	ICF	Share of non-empty miles in total miles driver that can be billed
4	Rate Per Mile	Rate_One	$/Mile	$1.2500	ICF	Expected revenue to be earned on billable, per-mile basis
5	Policy Rate Inc.	Policy_Rate	Rate	0.00%	Option-Specific	Change in industry revenues per mile caused by the HOS Option
6	Policy Miles Derate	Policy_Derate	Rate	0.00%	Option-Specific	Change in industry labor productivity caused by the HOS Option
7	**Expenses**	**Exp_One**	**Dollars**	**$61,170**	(8) + (9) + (12) + (15) + (18)	Sum of expenses
8	Amortization	Amort_One	Dollars	$23,721	-(34) + (35)	Sum of the debt payment (Truck_Pmt) and depreciation of the owner's downpayment (Truck_RA)
9	Fuel	Fuel_One	Dollars	$24,000	(2) * (1 + (6)) * (11) * (1 / (10))	Miles driven per year (MPY_One) adjusted for the change in productivity (1 + Policy_Derate) multiplied by the cost of diesel fuel (Diesel_Price) times the fuel economy per mile (1 / Econ_One)
10	*Fuel Economy*	*Econ_One*	*Miles/Gallon*	*6.00*	ICF	Typical diesel gas milage
11	*Cost Per Gallon*	*Diesel_Price*	*$/Gallon*	*$1.20*	ICF	Estimated cost of diesel fuel nationally
12	Maintenance	Maint_One	Dollars	$8,500	(13) + [(13) * (1 - (14)) /(2)] * (2) * (6)	Maintenance costs (Truck_Maint) adjusted for the change in the variable portion of maintenance costs (1 - Maint_Fixed) due to the change in VMT calculated as total, base variable cost divided by total miles driven (MPY_One) times the change in miles driven due to the change in productivity (MPY_One * Policy_Derate)
13	*Annual Cost*	*Truck_Maint*	*Dollars*	*$8,500*	ICF	Estimated annual maintenance costs
14	*Fixed Share*	*Maint_Fixed*	*Share*	*25%*	ICF	Estimated share of annual maintenance costs considered to be fixed, i.e., not based on VMT
15	Insurance	Ins_One	Dollars	$2,549	(16) + [(16) * (1 - (17)) /(2)] * (2) * (6)	Insurance costs (Truck_Ins) adjusted for the change in the variable portion of insurance costs (1 - Ins_Fixed) due to the change in VMT calculated as total, base variable cost divided by total miles driven (MPY_One) times the change in miles driven due to the change in productivity (MPY_One * Policy_Derate)
16	*Annual Cost*	*Truck_Ins*	*Dollars*	*$2,549*	ICF	Estimated annual insurance costs per driver
17	*Fixed Share*	*Ins_Fixed*	*Share*	*25%*	ICF	Estimated share of annual insurance costs considered to be fixed, i.e., not based on VMT
18	Licenses/Permits	Lic_One	Dollars	$2,400	ICF	Annual license and permit fees (assumed fixed under all Options)
19	**EBT**	**EBT**	**Dollars**	**$63,830**	(1) - (7)	Earnings Before Taxes (net of tax-deductible interest)
20	Tax Rate w/ FICA	Tax_Rate1	Rate	40%	ICF	Assumed aggregate local/state/federal income tax rate
21	Income Taxes	IncTax_One	Dollars	$25,532	(19) * (20)	Aggregate local/state/federal income taxes payable
22	**Net Disp. Income**	**NI_One**	**Dollars**	**$38,298**	(19) - (21)	Net income after taxes
23	Baseline Income	Base_One	Dollars	$38,298	(22): Base Value	
24	Delta	Est_Delta	Dollars	$0	(22) - (23)	HOS Option Net Income less Baseline Income (Base_One)
	Truck Capital Costs					
25	New Truck Cost	Truck_Cost	Dollars	$115,000	ICF	Cost of tractor/trailer
26	Initial Amort. Life	Truck_Amort1	Years	5.00	ICF	Amortization life of the tractor
27	Amortization Life	Truck_Amort	Years	5.00	(26) / (1 + (6))	Amortization life of the tractor/trailer (Truck_Amort1) adjusted for the change in productivity/VMT (1 + Policy_Derate)
28	Share Financed	Truck_Fin	Rate	80%	ICF	Share of purchase price financed to repaid as standard loan payment
29	Finance Rate	Truck_r	Rate	8%	ICF	Finance rate charged by lenders
30	Salvage Value	Truck_Salvage	Share	20%	ICF	Salvage value at the end of the five-year amortization period
31	Payment	Truck_Pmt	Dollars/Year	($19,121)	PMT function	Annual payment on loan adjusted for the salvage value
32	Residual Amort.	Truck_RA	Dollars/Year	$4,600	(25) * (1 - (28) / (27)	Annual depreciation of owner/operator contribution (Straight-Line)

Exhibit H-4
General Pro Forma Model Parameters/Assumptions

Financial Parameters	Name	Value	Units	Source
Tax Rate	Tax_Rate	40%	Rate	ICF, Represents aggregate federal/state/local corporate tax rate
Cash Interest Rate	Cash_Rate	4%	Rate	ICF, Applicable to Current Asset holdings of the firm
Short-Term Debt Rate	ST_Debt_Rate	6%	Rate	ICF, Applicable to Current Liability holdings of the firm
Long-Term Debt Rate	LT_Debt_Rate	8%	Rate	ICF, Applicable to Long-Term Debt holdings of the firm
Pre-Tax Equity Rate	Equity_Rate	20%	Rate	ICF, Assumes 12% after-tax equity rate of return
Pre-Tax WACC	WACC_PreTax	13%	Rate (By Firm)	Debt_Ratio * LT_Debt_Rate + (1 - Debt_Ratio) * Equity_Rate
Incremental Driver Cost Assumptions				
Fuel Economy	PF_Econ	6.00	Miles/Gallon	ICF
Fuel Cost	PF_Fuel_Price	$1.20	$/Gallon	
Annual Maintenance Cost	PF_Maint	$8,500	Dollars	ICF; See Chapter 6 - Additional computations made to convert analysis described in Chapter 6 to costs per driver
Fixed Share of Maintenance	PF_Maint_Fix	25%	Share	
Insurance Cost Per Driver	PF_Truck_Ins	$2,549	Dollars	ICF; See Chapter 6
Fixed Share of Insurance	PF_Ins_Fixed	25%	Share	
Licenses/Fees Per Truck	PF_Lic_One	$2,400	Dollars	
Parking Capital Per Driver	Pkg_Capex	$4,134	Dollars	ICF; See Chapter 6 - Additional computations made to convert analysis described in Chapter 6 to costs per driver
Parking O&M Cost Per Driver	Pkg_OM	$376	Dollars	
New Truck Cost	PFT_Cost	$115,000	Dollars	Assumes $115,000 initial cost for tractor/trailer set adj. for the net present value of the salvage value based on the Pre-Tax WACC (WACC_PreTax) and the new Amortization Life (PFT_Amort); Refer to Chapter 6
Initial Amort. Life	PFT_Amort1	7.00	Years	ICF; See Chapter 6
Amortization Life	PFT_Amort	7.29	Years	PFT_Amort1 / (1 + Delta_Prod); adj. for change in life of assets due to change in productivity
Salvage Value	PFT_Salvage	0%	Share of New	ICF; matches assumption of zero salvage assumed in Chapter 6
Churn Rate	Churn	25%	Percent	ICF; See Chapter 6
Cost Per Hire	Cost_Hire	$1,610	Dollars	
Tractors Per Driver	TD_Ratio	0.75	Ratio	ICF; See Chapter 6
Avg. Miles Per Tractor	Miles	120,000	Miles	
New Driver Wages	New_Wages	$30,525	Dollars	ICF; See Chapter 6 - Since the 4% value for Supv_to_Drivers ratio is applied to the labor cost, and not the quantity of labor, the wages for new drivers and supervisors are assumed to be the same for purposes of calculating cost in the model
New Driver Benefits	New_Benefits	31%	Percent	
Ratio of Supervisors to Drivers	Supv_to_Drivers	4%	Ratio	
New Supv. Wages	Supv_Wages	$30,525	Dollars	
New Supv. Benefits	Supv_Benefits	31%	Percent	
Current Driver OT Benefits	CD_Benefits	6%	Percent	
Number of Drivers in US Market	US_Drivers	3,000,000	Headcount	ICF; See Chapter 6
Elasticity of Labor Supply	Labor_E	5.00	Decimal	

Exhibit H-5
Overview of General Pro Forma Model Equations

#	Income and Cash Flow	Formula	Explanation
1	Operating Revenues	Base_Revenues * (1 + Delta_Rev) * (1 + Delta_Business)	Existing firm's Base_Revenues are adjusted to reflect the impact of changes in costs on industry wide revenues (Delta_Rev) and the inability to adapt incrementally based on the step function nature of hiring or firing employees on operations (Delta_Business)
2	Operating Expenses	(3) + (7)	
3	Depreciation	Sum of (4) to (6)	
4	*Depr. Existing Assets*	Reported value for depreciation expense	
5	*Depr. Longer-Life Existing*	(33) / PFT_Amort	New tractor/trailer equipment acquistions divided by the adjusted amortization rate based on change in mileage per tractor (PFT_Amort)
6	*Depr. New Assets*	C37/PFT_Amort	Avoided tractor/trailer equipment acquistions (due to the change in VMT per vehicle) divided by the adjusted amortization rate based on change in mileage per tractor (PFT_Amort)
7	Direct Operating Expense	(8) + (9)	
8	Existing Operations	Reported value for existing operation expense less depreciation	
9	*Incremental Operations*	Sum of (10) to (18)	
10	*Driver Recruitment*	Delta_Drivers * (1+Churn) * Cost_Hire	Change in the number of drivers (Delta_Drivers) times the direct cost to hire them (Cost_Hire) plus the additional burden the new drivers cause for on-going churn based on the existing churn rate (Churn)
11	*New Drivers*	Delta_Drivers * New_Wages * (1 + New_Benefits) * [1 + (Delta_US / US_Drivers) / Labor_E]	Firms experience two types of impacts on the wages associated with new drivers: (1) *Direct Wage Impact*: Change in the number of drivers (Delta_Drivers) times the direct wage (New_Wages) and benefits multiplier (New_Benefits); and (2) *Labor Supply Elasticity Impact on New Driver Wages*: The percentage change in demand for drivers at the national level (Delta_US) over the current demand (US_Drivers) is divided by the labor elasticity value (Labor_E) to determine the percentage change in new driver wage costs
12	*New Supervisors*	Supv_to_Drivers * Delta_Drivers * Supv_Wages * (1 + Supv_Benefits)	Change in the number of drivers (Delta_Drivers) times the ratio of supervisors to drivers (Supv_to_Drivers) determines the change in demand for supervisory labor which is multiplied by the direct wage (Supv_Wages) and benefits multiplier (Supv_Benefits) for supervisors
13	*Current Drivers*	CD_DiffSalary * Drivers * (1 + CD_Benefits) + Drivers * (Delta_US / US_Drivers) * New_Wages * (1 + New_Benefits) / Labor_E	Firms experience two types of impacts on the wages associated with current drivers: (1) *Direct Wage Impact*: Change in the salary earned by current drivers corresponding to the change in the productivity (CD_DiffSalary) times the number of existing drivers (Drivers) times the benefits multiplier for marginal labor (CD_Benefits) (2) *Labor Supply Elasticity Impact on Current Driver Wages*: The percentage change in demand for drivers at the national level (Delta_US) over the current demand (US_Drivers) is divided by the labor elasticity value (Labor_E) to determine the percentage change in new driver wage costs which is then multiplied by the number of drivers (Drivers) times the direct wage (New_Wages) and benefits multiplier (New_Benefits) to determine the overall change in wages for current drivers
14	*Vehicle Fuel*	Miles * Delta_Business * (1 / PF_Econ) * PF_Fuel_Price	Change in the amount of business caused by the step-function nature of adding/subtracting employees (Delta_Business) results in a change in the VMT and subsequent diesel fuel consumption based on the fuel economy in gallons per mile (1 / PF_Econ) times the fuel price in dollars per gallon (PF_Fuel_Price)
15	*Vehicle Insurance*	Delta_Drivers * PF_Truck_Ins * PF_Ins_Fixed + (Delta_Drivers + Drivers) * Delta_Business * PF_Truck_Ins * (1 - Ins_Fixed)	Change in Vehicle Insurance costs consists of two components: (1) *Fixed Costs*: A portion (PF_Ins_Fixed) of the insurance cost per driver (PF_Truck_Ins) is considered fixed per new driver (Delta_Drivers); and (2) *Variable Costs*: The remaining portion of insurance costs (PF_Truck_Ins * (1 - PR_Ins_Fixed)) vary based on the level of VMT by all drivers (Delta_Drivers + Drivers), where VMT is affected by the step-function nature of adding/subtracting employees (Delta_Business)
16	*Vehicle Licenses/Fees*	Delta_Trucks * PF_Lic_One	Change in the number of new tractors (Delta_Trucks) times the annual licensing costs per tractor (PF_LC_One)

Exhibit H-5 (Continued)
Overview of General Pro Forma Model Equations

#		Formula	Explanation
17	*Vehicle Maintenance*	Delta_Trucks * PF_Maint * PF_Maint_Fix + (Delta_Trucks + Tractors) * Delta_Business * PF_Maint * (1 - PF_Maint_Fix)	Change in Vehicle Maintenance costs consists of two components: (1) *Fixed Costs*: A portion (PF_Maint_Fixed) of the maintenance cost per tractor (PF_Truck_Maint) is considered fixed per new tractor (Delta_Trucks); and (2) *Variable Costs*: The remaining portion of maintenance costs (PF_Truck_Maint * (1 - PR_Maint_Fixed)) vary based on the level of VMT by all drivers (Delta_Trucks + Tractors), where VMT is affected by the step-function nature of adding/subtracting employees (Delta_Business)
18	*Parking Lot Maintenance*	Delta_Drivers * Pkg_OM	Change in the number of new drivers (Delta_Drivers) times the annual costs per driver of maintaining parking for both new tractor/trailer sets, as well as auto parking for new drivers (Pkg_OM)
19	Net Non-Operating Revenue	Difference between reported values for non-operating income and expense	
20	EBIT	(1) - (2) + (19)	Earnings Before Interest and Taxes (Measure of Profitability)
21	*Operating Ratio*	1- ((1) - (2)) / (1)	Share of Operating Expense in Operating Revenue
22	Interest: Existing Assets	Blue Book Firms: Reported Value RMA-Based Data: -Cash_Rate * (40) + ST_Debt_Rate * (49) + LT_Debt_Rate * (54)	For firm level data, the actual value is used, for non-firm-level data, e.g., RMA data, interest expense is estimated by the pro forma as the assumed short-term debt rate (ST_Debt_Rate) times total Current Liabilities plus the assumed long-term debt rate (LT_Debt_Rate) times total Long-Term Debt: Existing less the assumed cash rate (Cash_Rate) times total Current Assets
23	Interest: New Assets	LT_Debt_Rate * (55)	Interest due on new investments based on the Long-Term Debt Rate (LT_Debt_Rate)
24	EBT	(19) - (21)	Earnings Before Taxes (net of tax-deductible interest)
25	*Profit Before Taxes*	(24) / (1)	EBT in Operating Revenues
26	Taxes: Existing	Blue Book Firms: Reported Value RMA-Based Data: Tax_Rate * (Revenues - (4) - (8) + (19) - (22))	For firm level data, the actual value is used; for non-firm-level data, e.g., RMA data, taxes are estimated by the pro forma as the assumed corporate income tax rate (Tax_Rate) times EBT for existing business
27	Taxes: New	((1) - Revenues - (5) - (6) - (9) - (23)) * Tax_Rate	Taxes on the change in EBT resulting from the HOS option are estimated by first subtracting the baseline revenues (Revenues) from the adjusted revenues (1), and then netting off the incremental costs associated with new depreciation, operating expenses, and interest
28	**Net Income**	(24) - (26) - (27)	Net shareholder operating profit of the firm
29	*Profit After Taxes*	(28) / (1)	Net Income in Operating Revenues as a measure of firm Profitability
30	Depreciation	(3)	Depreciation is added back to cash flows available to cover interest
31	Interest (Net of Tax)	Sum of ((22) + (23)) * (1-Tax_Rate)	Interest after taxes is added back to cash flows to cover interest
32	**Sub-Total Cash Flows**	Sum of (28), (30) and (31)	Cash flow available to cover interest payments
33	*Debt Coverage Ratio*	(32) / Sum of ((22) + (23))	Ratio measures ability of the firm to cover estimated interest payments out of cash flow; a value less than one indicates a firm at risk for default
34	Incremental Investments	Sum of (32) to (34)	Total incremental investments to be financed by debt and equity
35	*New Trucks*	PFT_Cost * Delta_Trucks	Change in the number of tractor/trailer sets required for new drivers (Delta_Trucks) times the cost per set (PFT_Cost)
36	*Avoided Trucks*	-Tractors * (PFT_Amort / PFT_Amort1 - 1) * PFT_Cost / PFT_Amort1	Changes in the ratio of the adjusted rate of vehicle amortization (PFT_Amort) to the existing level (PFT_Amort1) times the replacement cost of existing vehicles (Tractors * PFT_Cost) yields the total tractor cost to be distributed over the amortization life of the asset (PFT_Amort1)
37	*Parking*	Pkg_Capex * Delta_Drivers	Change in the number of new drivers (Delta_Drivers) times the capital costs per driver of installing new parking for both new tractor/trailer sets, as well as auto parking for new drivers (Pkg_Capex)
38	**Free Cash Flows**	(32) - (34)	Free Cash Flows required in year one

Exhibit H-5 (Continued)
Overview of General Pro Forma Model Equations

#	Balance Sheet	Formula	Explanation
39	**Assets**	(40) + (43) + (46) + (47)	
40	Current Assets	(41) + (42)	
41	*Cash & Equivalents*	Reported value for cash & equivalents	
42	*Other Current Assets*	Reported value of other current assets	
43	Net Fixed Assets	(44) + (45)	
44	*Existing Fixed Assets*	Reported value for existing fixed assets	
45	***Incremental Fixed Assets***	(34) - (5) - (6)	Sum of Incremental Investments less the first year of depreciation attributable to incremental investments
46	Net Intangibles	Reported value for existing net intangibles	
47	All-Other Non-Current Assets	Reported value for existing other non-current assets	
48	**Liabilities**	(49) + (53) + (56) + (57) + (58)	
49	Current Liabilities	(50) + (51) + (52)	
50	*Short-Term Notes Payable*	Reported value for short-term notes payable	
51	*Current Maturities*	Reported value for current maturities	
52	*Other Current Liabilities*	Reported value for other current liabilities	
53	Long-Term Debt	(54) + (55)	
54	*Existing LTD*	Reported value for existing long-term debt	
55	***Incremental LTD***	Debt_Ratio * (45: Incremental Fixed Assets)	Change in Incremental Fixed Assets times the share of financing from debt based on the firm's debt ratio (Debt_Ratio = LTD / (LTD + Existing Equity))
56	Deferred Taxes	Reported value for deferred taxes	
57	All-Other Non-Current Liabilities	Reported value for other non-current liabilities	
58	Shareholder Equity	(59) + (60)	
59	*Existing Equity*	Reported value for existing equity	
60	***Incremental Equity***	(1 - Debt_Ratio) * (42: Incremental Fixed Assets)	Change in Incremental Fixed Assets times the share of financing from equity based on one minus the firm's debt ratio (Debt_Ratio = LTD / (LTD + Existing Equity))
#	**Firm Parameters**	**Formula**	**Explanation**
61	Base Revenues [Base_Revenues]	Reported value for revenues	
62	Base Total Assets [Total_Assets]	Reported value for total assets (equals total liabilities)	
63	Total Statements	Reported value for number of statements; 1 if firm-level	
64	Tractors [Tractors]	Reported value for number of tractors (Blue Book) or estimated (RMA) based on Base Revenues divided by an assumed value for revenues per tractor rounded down to the nearest whole tractor (see Explanation)	Data for small firms (less than $3 million in revenues) based on assumption of $125,000 per tractor; else $165,000 per tractor for firms above $3 million in revenues
65	Est. # of Drivers [Drivers]	ROUNDDOWN (Tractors / TD_Ratio, 0)	Number of Tractors divided by the ratio of tractors to drivers (TD_Ratio) rounded down to nearest whole driver
66	Debt Ratio [Debt_Ratio]	Estimated from observed data	Estimated from firm data as LTD / (LTD + Existing Equity)
#	**Policy Variables**	**Formula**	**Explanation**
67	Change in Productivity [Delta_Prod]	Based on estimated percentage change by HOS rule	See Section 9 in the analysis
68	Change in Revenues [Delta_Rev]	Based on estimated percentage change by HOS rule	
69	Change in Number of US Drivers [Delta_US]	Based on estimated percentage change by HOS rule	
70	Diff. Salary of Current Drivers [CD_DiffSalary]	Based on estimated percentage change by HOS rule	
71	Change in # of Drivers [Delta_Drivers]	Model optimizes for the incremental number of whole employees to add or subtract based on the most profitable option subject to the Change in Productivity given all of the other model inputs, i.e., the model does not assume a continuous function for adding drivers, but adds drivers in a step-wise manner *Ex. 1*: A 25-person firm would like to add 2.5 employees to maintain its revenues assuming a 10% decrease in productivity, but may only add 2 whole employees, forgoing the revenues associated with the 0.5 labor equivalents, or 20% of the 10% reduction in productivity, resulting in a 2% reduction in business *Ex. 2*: A 4-person firm would like to lay off 0.4 employees to maintain its revenues assuming a 10% increase in productivity, and has the option of either laying off one FTE or not; in the latter scenario, business revenues and costs are unaffected except for macroeconomic impacts *Implications*: As firms become larger, the impact of this effect diminishes *Modeling Convention*: The model tests to see if adding or subtracting the last, marginal driver is profitable or not, i.e., whether or not the firm should add a full driver to cover the 0.5 labor equivalent requirement in Ex. 1	
72	% Business Lost Due to Step [Delta_Business]		
73	Change in # of Trucks [Delta_Trucks]	Delta_Drivers	Assumes a 1:1 ratio of new tractors to new drivers

Exhibit H-6
Summary of TTS Blue Book Data by Size Category

# OF TRACTORS	ANNUAL REVENUES[1]	# OF FIRMS	MEAN REV./ TRACTOR	MEDIAN REV./ TRACTOR	MEAN NO. OF TRACTORS[2]	MEDIAN NO. OF TRACTORS
20-50	$3 MM to $7.5 MM	753	$170,477	$152,080	34	34
51-145	$7.5 MM to $21 MM	660	$153,208	$139,023	84	78
146-550	$21 MM to $80 MM	227	$149,396	$138,211	249	222
551+	$80 MM+	62	$149,324	$143,259	1552	1063

[1]Median revenue per tractor of $145,000 was used to define categories.
[2]Numbers are rounded

The database was purged of entries violating the constraints outlined in Exhibit H-7, where the database contained 2,681 firms initially. Firms were ranked into quartiles based on profitability (as measured by net income divided by operating revenues) within each firm-size category once unusable data points were purged. ICF examined the firms lying on the boundaries between each quartile (lower (25%), median (50%), and upper (75%) and selected a representative firm from among these firms. These firms are used in the analysis for determining the relative financial impact by size category and current financial well-being.

The data from RMA are provided for the average within each size category and are based on a sample of firms. A value of $125,000 was used to determine the number of tractors in these firms since the number of tractors or drivers is not provided by this source. This differs from the $145,000 reported above based on the assumption that these smaller firms bear a closer resemblance to the single-tractor owner/operators than the larger size firms. All other data required for the analysis was available. Quartile data provided by RMA were not sufficient to allow for an evaluation of the impacts by quartile.

Exhibit H-7
ICF TTS Blue Book Data Processing Rules

DATA CONSTRAINT	REASON FOR REMOVAL	# FIRMS REMOVED
General Freight, Less-than-truckload (LTL) Household Goods Carrier Private Trucking, Compensated Interoperate Hauling General Freight, unknown as to whether LTL, TL, or Local General Freight, Local Cartage	The HOS rule is not expected to affect these segments significantly	475
Firms reporting zero tractors	Unable to characterize operation with respect to the number of tractors	199
Firms showing more trucks than tractors Firms showing the same number of trucks and tractors Outliers (more than 50 trucks)	Trucks (as compared to tractors) may be providing additional value-added services not related to long-haul operations, increasing revenue per tractor calculations	75 16
Firms showing less than 20 tractors	Inconsistent with the minimum revenue requirement in the Blue Book	189

DATA CONSTRAINT	REASON FOR REMOVAL	# FIRMS REMOVED
Firms having non-operating revenues in excess of gross revenues	Most likely an error in reporting or recording of the revenue data	10
Firms showing extremely high revenues per tractor (in excess of $500,000)	Firms may be providing other services in addition to long-haul operations	30

Exhibit H-8 compares the number of firms within each firm size category in the TTS Blue Book sample to the national estimates developed by this study as part of its industry overview presented in Chapter 3. The results show that the TTS Blue Book data provide a useful representation of firms at the national level for the larger sized firms. The residual tractors size categories in Chapter 3 are 1 to 5 and 6 to 24 tractors with 39,824 and 7,154 companies, respectively. The data on smaller firms are not easily obtained, as evidenced by the presence of only 77 and 141 firms in the samples for the two smallest sized firms (2 to 9 and 10 to 19 tractors), respectively.

Exhibit H-8
Comparison of TTS Blue Book and ICF National
Truck Load (TL) Motor Carrier Firm Population Estimates

TTS BLUE BOOK				CHAPTER 3			
SIZE CLASS	COMPANIES	PERCENT	CUM. %	SIZE CLASS	COMPANIES	PERCENT	CUM. %
20-50	753	44%	44%				
51-145	660	39%	83%	25-99	3,843	75%	75%
146-550	227	13%	96%	100-500	1,076	21%	96%
550+	62	4%	100%	500+	178	4%	100%
Totals	1,702			Totals	5,097		

APPENDIX I. REMI MODEL

ICF Consulting used the REMI Policy Insight®, the leading forecasting and policy analysis model during task. REMI helps to answer "what if...?" questions about the effect of policy initiatives on the economy of local regions. The model is research and development, which is subject to peer review and published in academic journals. REMI Policy Insight is currently used by hundreds of governmental agencies, universities, and others.

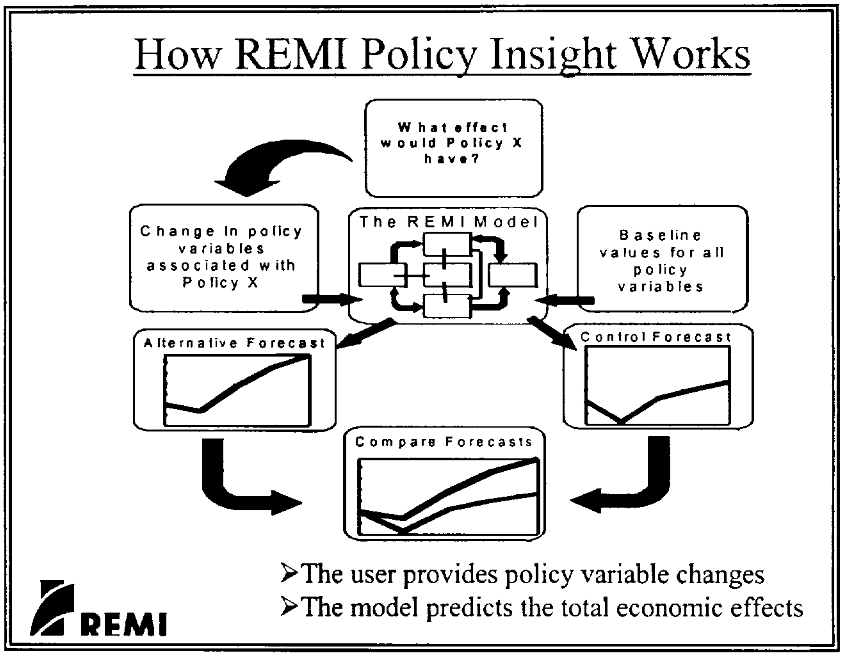
REMI's founder, Dr. George I. Treyz, developed the methodology used in REMI's socioeconomic modeling system in order to improve the quality of research-based decision-making in the public and private sectors. A research team currently led by Drs. George and Frederick Treyz continues to enrich and deepen REMI's powerful dynamic analytic engine. The latest version is based in part on a REMI prototype set forth in the November 2000 issue of the Journal of Regional Science. It is designed for regional areas of varying sizes in the U.S., the E.U., and Canada.

The forecasting and policy analysis system includes key econometric estimates and integrates inter-industry transactions, long run equilibrium features, and the new economic geography. It includes: substitution among factors of production in response to changes in relative factor costs; migration responses to changes in expected income; labor participation rate responses to changes in real wage and employment conditions; wage rate responses to labor market changes; consumer consumption responses to changes in real disposable income and commodity prices; and local, regional, and market shares responses to changes in regional production costs and agglomeration economics.

REMI Policy Insight contains a base case forecast from which alternative policies are simulated for changes in energy policies. The REMI base case forecast is founded on REMI's detailed compilation and analysis of all publicly available, regional data. The forecasts take into account national trends such as the BEA forecast of productivity, the Bureau of Labor Statistics' (BLS) forecast of the inter-industry input-output relationships to 2008, and a 2-year business cycle forecast from the University of Michigan. These national trends are reconciled to the state and county level through the application of value-added and employment data. The base case represents the scenario in which the current trends within the region continue subject to changes in the national trends.

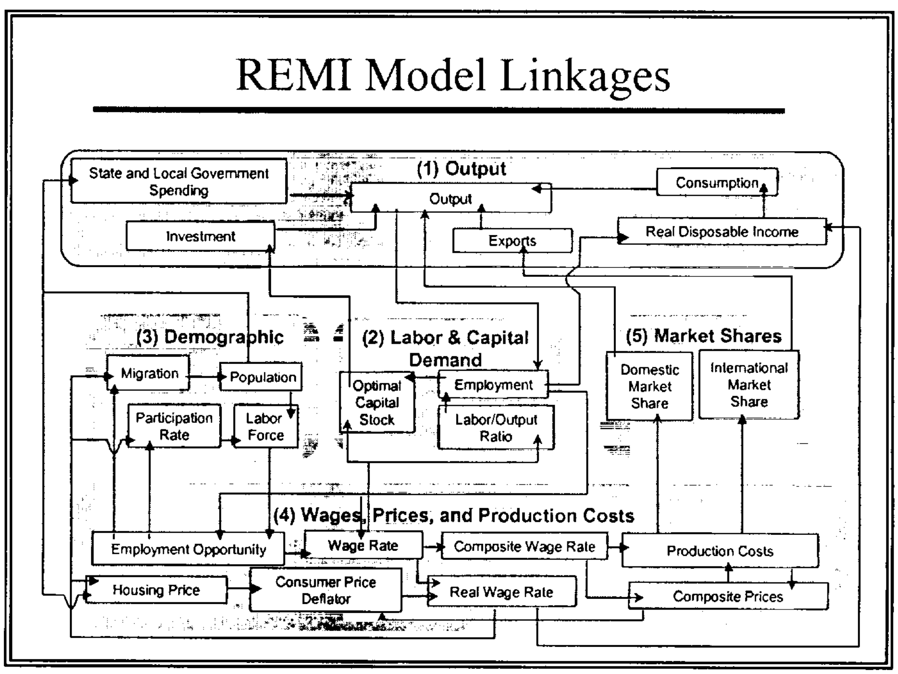
The REMI Policy Insight's unique power is to generate realistic year-by-year estimates of the total regional effects of any specific policy initiative. A wide range of policy variables allows the user to represent the policy to be evaluated while the explicit structure in the model helps the user to interpret the predicted economic and demographic effects. The model is calibrated to many sub-national areas for policy analysis and forecasting, and is available in single- and multi-area configurations. Each calibrated area (or region) has economic and demographic variables, as well as policy variables so that any policy that affects a local economy can be tested. A flowchart of the model is presented below in Exhibits I-1 and I-2.

Exhibit I-1
How REMI Policy Insight Works



Source: Electronic file from REMI, 2002.

Exhibit I-2
REMI Model Linkages



Source: Electronic file from REMI, 2002.

APPENDIX J.
SAMPLE OF INFORMATION FOR MODELING SHORT-HAUL SCHEDULES

Contrast of the on-duty cycles of long-haul and short-haul drivers in the beverage industry. Data from Jim York (personal communication, 3/28/97) reproduced from Hanowski, *et al.*, 2000.

Typical On-Duty Cycle of Long-Haul Driver in the Beverage Industry	Typical On-Duty Cycle of Local/SH Driver in the Beverage Industry
Arise from sleeper-berth at 5:00 am.	Report to work at 5:00 am and review daily route assignment sheet.
Perform pre-trip inspection and update record of duty status (logbook).	Inspect beverage bays to ensure the proper loading of produce.
Drive 50-100 miles to consignee's delivery facility.	Correct any product shortages or overages.
Notify consignee of shipment arrival and provide appropriate shipping papers.	Conduct pre-trip vehicle inspection.
Supervise unloading of the vehicle.	Complete necessary pre-trip paperwork.
Obtain load delivery receipt from consignee and complete appropriate paperwork.	Drive 15-30 miles to first delivery stop (e.g., small grocery or convenience store).
Drive 30-50 miles to beverage bottling facility.	Check route assignment sheet to verify quantity and type of requested delivery.
Provide order information to beverage shipping department.	Unload product from beverage bays onto two-wheel cart.
Supervise loading of the vehicle and ensure load is adequately secure.	Rotate display stock as required.
Obtain shipping papers and complete appropriate paperwork.	Place delivered product on display shelves.
Drive 300-400 miles to beverage distribution facility or to the end of a ten-hour duty cycle.	Collect recycled cans and bottles and load in appropriate truck bay.
Notify consignee of shipment arrival.	Complete sales invoice and give copy to customer.
Supervise the unloading of the vehicle.	Drive on; perhaps three miles to next stop.
Update record of duty status and end of shift at approximately 6:00 pm.	Repeat steps 7-13 for the balance of assigned route (e.g., 30-50 stops per on-duty cycle is not uncommon).
	Drive 30-50 miles back to terminal
	Unload recycled containers, and empty pallets/waste from beverage bays.
	Assist in reloading as necessary (Note: many beverage operations have dedicated crews to reload these vehicles during the evening hours. However, the driver may perform some or all of the reloading in some instances.)
	Complete daily route summary and other required paperwork.
	Depart for home some time after 6:00 pm.

Source: Table 4 from Hanowski, *et al.*, 2000, Page 8

APPENDIX K.
INDUSTRY EXPERTS AND SOURCES

For information on, and understanding of, operating and business characteristics and behavior of trucking firms, we relied on industry experts on the consulting team together with discussions with individuals in the trucking business, for-hire and private, and some individuals who are very close observers of the trucking business.

The industry experts on our team were Garland Chow, George Edwards, and Paul Roberts.

Garland Chow is a professor of logistics at the University of British Columbia. He has studied logistics operations and trucking operations in close detail for many years. He has worked as a consultant to logistics and trucking firms and to governments with an interest in these matters.

George Edwards is a consultant to trucking firms and private carriers and has managed both for-hire and private operations.

Paul Roberts has studied logistics and specific logistics operations and problems for many years. He has experience in trucking management as well as in analytical work.

Individual contacts in the industry are listed below.

- Greg Brown, B. R. Williams Trucking
- Jerry Crews, Deaton, Inc.
- Mack Dove, AAA Cooper Transportation
- Carroll Enderby, Douglass Distributing
- Jack Fricks, B & G Supply
- John Gentle, Owens Corning
- Steve Gordon, Gordon Trucking
- Jim Haberstroh, Continental Van Lines
- Mitch Land, Shaw Transport
- Chris Licht, Covenant Transport
- Neil Lowery, R. B. Burnham Van Services
- Timothy Lynch, Motor Freight Carriers Association
- Rich Meehan, Heartland Express
- Ken NeSmith, Wellborn Cabinet
- Steven O'Kane, New Penn Motor Express
- Clifton Parker, G & P Trucking
- Robert Petrancosta, Conway Transportation Services
- Gary Petty, National Private Truck Council

- Pat Quinn, U. S. Xpress
- Barry Riley, United Carriers
- Rick Robinson, Robinson Transport
- Hubert Rogers, Golden Flake Snack Foods
- Ronald Roth, Transportation Technical Services
- Fred Russell, AAA Associates Moving and Storage
- R. Martin Scroggins, MAGNATRAN Corporation
- John Siebert, Owner Operator Independent Driver Association
- Debra Stone, McKee Foods
- David Stubblefield, ABF Freight System
- Harry Winters, United Parcel Service