REGULATORY IMPACT ANALYSIS
FOR
HOURS OF SERVICE OPTIONS

Prepared by:

Federal Motor Carrier Safety Administration

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LIST OF EXHIBITS

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LIST OF ACRONYMS

ATA	American Trucking Associations
BEA	Bureau of Economic Affairs
CMV	Commercial Motor Vehicle
DFACS	Driver Fatigue, Alertness, and Countermeasures Study
DOT	Department of Transportation
ES	Executive Summary
FARS	Fatality Analysis Reporting System
FMCSA	Federal Motor Carrier Safety Administration
GDP	Gross Domestic Product
GES	General Estimates System
HOS	Hours of Service
IIHS	Insurance Institute for Highway Safety
LCM	Logistics Cost Model
LH	Long-Haul
LTL	Less-than-Truckload
MCMIS	Motor Carrier Management Information System
NAICS	North American Industrial Classification System
NHS Act	National Highway System Designation Act of 1995
NHTSA	National Highway Traffic Safety Administration
NPRM	Notice of Proposed Rulemaking
OOIDA	Owner-Operators Independent Drivers Association
OTR	Over the Road
PVT	Psychological Vigilance Task
RIA	Regulatory Impact Analysis
SBA	Small Business Administration
SH	Short-Haul
SPM	Sleep Performance Model
TL	Truckload
TOT	Time on Task
UMTIP	University of Michigan Trucking Industry Program
UPS	United Parcel Service
VIUS	Vehicle Inventory and Use Survey
VMT	Vehicle Miles Traveled
VPI	Virginia Polytechnic Institute
VSL	Value of Statistical Life
WRAIR	Walter Reed Army Institute of Research
WRAIR-SPM	Walter Reed Army Institute of Research – Sleep Performance Model

EXECUTIVE SUMMARY

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 (HOS) regulations. The HOS regulations address the number of hours that a commercial motor vehicle driver (CMV) may drive, and the number of hours a CMV driver may be on duty, after which driving is prohibited until a minimum off-duty rest period is taken.

A new HOS rule was promulgated on April 28, 2003 (68 FR 22456) and implemented on January 4, 2004 with the goal of reducing the incidence of fatigue-related crashes. That rule increased the required rest between tours of duty from 8 to 10 hours (which could be split into two sleeper-berth periods under some conditions), allowed drivers to restart their calculation of duty hours in a multi-day period if they took a continuous off-duty break of at least 34 hours, and lengthened the driving period between offduty rest periods from 10 to 11 hours.

After the new rule had been in effect for several months, it was vacated by the United States Court of Appeals for the District of Columbia Circuit (D.C. Circuit). [*Public Citizen et al. v. Federal Motor Carrier Safety Administration*, 374 F.3d 1209, at 1216.] The D.C. Circuit found, on July 16, 2004, that FMCSA had not considered effects on drivers' health. It also expressed concerns about the 11th driving hour, the restart of the multi-day duty-hour calculation, the use of sleeper berths to split the rest period, and the lack of consideration of electronic on-board recorders. In response to the court's action, Congress extended the 2003 rule for a year, in order to give FMCSA a chance to revisit the issues cited by the court. FMCSA then re-proposed the rule as published in 2003 and sought comments. (70 FR 3339, Jan. 24, 2005) On August 25, 2005, FMCSA published a new HOS rule that retained most of the provisions of the 2003 rule. [70 FR 49978, Aug. 25, 2005]. One major change required drivers using sleeper berths to spend 8 consecutive hours in the berth and take an additional 2 hours either off duty or in the berth; this 2-hour period must be counted against the 14-hour on-duty limit. The 2005 rule also provided relief to some short-haul operations using medium and medium-heavy trucks.

The August 2005 HOS rule was then challenged on several grounds, separately by Public Citizen and the Owner-Operators and Independent Drivers Association. On July 24, 2007, the Court rejected OOIDA's arguments, which focused on the sleeper berth provision, but ruled in favor of Public Citizen and vacated the 11-hour driving time and 34-hour restart provisions (Owner-Operator Independent Drivers Association, Inc. v. Federal Motor Carrier Safety Administration, 494 F.3d 188 (D.C. Cir. 2007). In an order filed on September 28, 2007, the Court then granted in part FMCSA's motion for a stay of the mandate. The Court directed that issuance of the mandate be withheld until December 27, 2007.

On December 17, 2007 (72 FR 71247), FMCSA published an Interim Final Rule (IFR) amending the Federal Motor Carrier Safety Regulations effective December 27, 2007, to allow CMV drivers up to 11 hours of driving time within a 14 hour, non-extendable window from the start of the workday, following 10 consecutive hours off duty. The IFR also allowed motor carriers and drivers to restart calculations of the weekly on-duty time limits after the driver has at least 34 consecutive hours off duty. The FMCSA explained that the IFR reinstating the 11-hour limit and the 34-hour restart was necessary to prevent disruption to enforcement and compliance with the HOS rules when the court's stay expired, and would ensure that a familiar and uniform set of national rules governed motor carrier transportation. The FMCSA requested public comments on all aspects of the IFR, and stated that it would issue a final rule in 2008.

Public Citizen immediately requested the District of Columbia Circuit to invalidate the IFR. However, on January 23, 2008, the court issued a per curiam order denying Public Citizen's request. On February 7, 2008, FMCSA received a request to extend the public comment period. On February 20, 2008, FMCSA extended the public comment period until 2008 (73 FR 9233).

ES.1 Options

This analysis considers and assesses the potential consequences of two potential regulatory options.

Option 1 is the current rule. It allows up to 11 hours of driving, allows a new 7- or 8-day period to begin after a 34-hour restart break, and some splitting of off-duty periods using sleeper berths. The option constrains the use of sleeper berths, though, to ensure that each sleeper berth period is at least 8 hours, and is supplemented by a 2-hour break that may be outside the sleeper berth.

Option 2 is more stringent than Option 1, limiting driving to 10 (rather than 11) hours in a tour of duty, and eliminating the use of the restart break. The sleeper berth provisions are the same as in Option 1.

Both options retain the short-haul provision contained in the 2005 rule, namely, short-haul operators of vehicles not requiring a commercial driver's license (CDL), or typically those of less than 26,000 lbs gross vehicle weight rating (GVWR), and remaining within a 150 mile radius of their base, may keep timecards in lieu of logbooks and may be on-duty up to 16 consecutive hours two days during a seven-day work week.

ES.2 Overview of the Analysis

The analysis of costs recognizes that the different provisions of the options will affect carrier operations in complex and interacting ways. It also recognizes that these effects will depend strongly on the carriers' baseline operating patterns, which vary widely across this diverse industry. To produce a realistic measurement of the impacts of each option, we divided the industry into broad segments, collected information on operations within these segments, and then created a model of carrier operations as they are affected by HOS rules. Given the very wide array of operational patterns, it was necessary to limit the analysis to the most important cases.

The model was first loaded with data representative of shipping patterns and carrier cost structures, and tested to ensure that it could realistically simulate typical lengths of haul, empty mile ratios, and productivity. It was then set up to cover most important cases, under constraints representing each option, and used to simulate carrier operations under different conditions and HOS rules. We then analyzed the data representing the simulated operations, using changes in miles driven as a measure of productivity impacts. Output measures from individual runs were weighted to give a realistic representation of the affected industry, including the drivers' use of the most important provisions of the options. The weighted changes in productivity from this procedure were then used to estimate the cost increases imposed on the industry by each option, using an analysis of the changes in wages and other costs likely to result from changes in productivity. These productivity-related costs were combined with transition costs associated with shifting to new rules to produce estimates of total social costs.

Safety impacts were measured by feeding the on duty and driving schedules from the carrier simulation model into an operator fatigue model to project driver effectiveness levels, and then using the fatigue model results to estimate the resulting changes in crash risks under each HOS option and for the different operations cases. Changes in fatigue-related crash risks, calibrated to match realistic levels, were then multiplied by the value of all affected crashes to yield estimates of total benefits.

Due to time constraints, the modeling of Option 2 was conducted using slightly different assumptions about the rule: sleeper berth splitting was not permitted at all, and the length of the restart was extended to 58 hours but not eliminated. Neither of these differences is expected to have large effects on either costs or benefits; furthermore, they act in opposite directions. Thus, the net impacts of the Option 2 as modeled are likely to be very close to the impacts that would have been seen if the Option 2 had been modeled exactly as specified. In addition, several issues in the benefits analysis that were pointed out in the appeals process have led to a reanalysis of the effects of the options on the crash risks associated with long driving shifts. Again, due to time constraints, the existing analysis has been carefully adjusted rather than entirely redone. These adjustments are discussed in detail in Appendix (V).

This RIA has been updated from the 2007 HOS RIA in several ways. Dollar values are now expressed in 2005 dollars rather than 2004 dollars; the industry population has been updated to account for growth in numbers of long-haul (LH) drivers over the past six years; estimated changes in productivity and crashes have been corrected slightly to include effects on the LTL sector; and the value of crash reductions has been updated using newer crash information and a revised (higher) value of statistical life.

ES.3 RESULTS

The results of the simulation modeling of LH operations are shown in Exhibit ES-1, which presents impacts for drivers in operations of different average lengths of haul (short regional or SR, long regional or LR, and long-haul or LH), different degrees of schedule regularity (random or regular), different work weeks (those working five as opposed to six days per week), and for solo drivers and teams. No distinctions are made for differences in sleeper berth usage because the only options considered restricted the splitting of sleeper berth periods. The impacts on driver productivity of Option 2, relative to Option 1, varied widely for runs simulating these different types of operations.

Exhibit ES-1 Estimated Changes in Long-Haul Productivity by Option and Case			
			Option 2 Compared to Option 1
Run characteristics			**Relative Reduction in driving hours**
For-hire, random		SR	24.10%
		LR	21.40%
		LH	20.40%
Regular Routes (Private TL, LTL, regular for-hire)	Full weekend off	Weekly route	16.10%
		Daily route**	-2.00%
	Six-day work week	Weekly route	29.20%
		Daily route	8.90%
Team drivers*			5.00%

* This impact estimate was based on simplified scenarios rather than model runs.
** These negative impacts are the results of random factors in the simulation, and would not persist if they were repeated a large number of times.

Because it limits driving hours and requires more time off between multi-day work periods, there is a substantial productivity loss caused by Option 2 relative to Option 1 in almost all cases. The impacts of changes in the restart period are particularly large for the random drivers, whose lack of a regularly scheduled off-duty period means that a short restart can be very advantageous. For Option 2, team drivers were expected to lose 5 percent of their productivity as a result of the loss of the 11^{th} hour of driving: even if the members of a driving team want to average only 10 hours of driving per day, random factors will tend to push them slightly over 10 hours on some days, and slightly under on other days. If they are limited to no more than 10 hours, however, they will tend to average somewhat less than 10 hours as a result of the times when they cannot use all of the 10 hours that are permitted.

The productivity impacts shown in ES-1 were weighted to produce an industry-wide estimate of average impacts using data on the prevalence of different operating patterns and different degrees of use of several important features of the existing HOS rules. The weighted productivity impacts, which are shown in Exhibit ES-2, came to -7.30% for Option 2.

The impact of these changes in productivity were estimated using analyses of the changes in costs (for labor and equipment) as a function of changes in hours worked, due to the need to hire more drivers as the productivity of each existing driver is reduced. These analyses showed that each one percent change in driver productivity is associated with just under $300 million in costs using a population estimate based on 2000 and 2004$. Updating to a larger 2005 population and 2005$ raises the cost of each one percent change in productivity to $335 million. Multiplying the weighted average productivity impacts by the costs per percent decrease in productivity yields $2.443 billion for the incremental effects of Option 2.

The total costs of the options on the LH sector, relative to Option 1, are shown in Exhibit ES-2. ES-2 also shows anticipated changes in LH drivers (not counting small changes related to mode shift).

Exhibit ES-2 Incremental Annual Costs of Option 2 for Long-Haul (LH) Operations Relative to Option 1	
	Option 2
Change in LH Productivity	-7.30%
Change in Annual Costs due to Productivity Loss (millions of 2005$)	$2,443
Increase in Numbers of Drivers (thousands)	120

Source: FMCSA analysis.

Crash Risk Results by Operational Case

The results of the crash risk modeling are presented in the table below, after scaling the results to yield an average fatigue-related value of approximately 7 percent in Option 1. These results were also adjusted slightly to correct issues in the implementation of the estimated time-on-task effect; these adjustments are discussed in detail in Chapters 5, 6, and Appendix (V). Overall, the impacts are relatively small, as might be expected for options that are making marginal changes in an existing rule. Weighting the crash risk results in the same manner as the productivity results, we found the overall changes in crash risks to be small. Option 2 resulted in a risk reduction of about 0.63 percent.

Exhibit ES-3 Incremental Crash Risk Estimates			
			Option 2 Compared to Option 1
Run characteristics			**Relative Change in Crash Risk**
For-hire, random		SR	1.1%
		LR	-6.9%
		LH	-9.3%
Regular routes (Private TL, LTL, regular for-hire)	Full weekend off	Weekly	0.2%
		Daily	-0.7%
	Six-day work week	Weekly	-0.7%
		Daily	-0.9%
Team drivers*			-0.7%
Weighted Average Impacts (raw)			-1.2%
Weighted Average Impacts (scaled)			-0.5%
Weighted Average Impacts (scaled and adjusted using revised time-on-task approach)			-0.63%

* This impact estimate was based on simplified scenarios rather than model runs.

Value of the Crash Risk Changes

These percentage changes in risk were valued by multiplying them by an estimate of the total annual damage associated with heavy-duty long-haul truck crashes, updated to account for a slight increase in total crashes, and reestimated damages per crash using a higher value of a statistical life. This total was multiplied by the percentage of total damages that were caused by the long-haul segment, yielding just over $34 billion. The reduction in risk attributable to Option 2, given this total value, is about 0.63% * $34 billion or about $214 million per year.

Net Costs by Option

Exhibit ES-4 summarizes the annualized costs, benefits, and net costs of Option 2 relative to Option 1.

Exhibit ES-4
Net Incremental Annual Costs of Option 2 Relative to Option 1
(millions of 2005$)

Total Annual Incremental Cost	$2,443
Total Crash Reduction Benefits	$214
Net Annual Costs	$2,229

Source: FMCSA analysis.

Sensitivity Analysis for a 10-hour Driving Limit

In addition to examining Option 2 relative to Option 1, a variant of Option 1 was considered. This variant combined the other features of Option 1 with the 10-hour driving limit included in Option 2. This option was found to be considerably less cost-effective than the basic version of Option 1, as shown in the first row of Exhibit ES-5. The 10-hour variant has net costs of about $540 million per year, after correcting the analysis of TOT-related fatigue for problems uncovered in the appeals process and updating the size of the industry and the value of crash reductions.[1] The conclusion that imposing a 10-hour driving limit was not cost-effective was tested by reexamining costs and benefits under a series of sensitivity assumptions, which are shown in the other rows of Exhibit ES-5. Doubling the assumed use of the 11th hour increased the net costs of the 10-hour variant from $540 million to $1,080 million, making Option 1 with 10 hours of driving even less cost effective. Raising the value for each statistical life saved from about $5.5 million to over $10 million improved the relative cost effectiveness of Option 1 with 10 hours driving, but it was still not cost beneficial (with net costs of $432 million). Also, raising the relative risk of a fatigue-related crash in the 11th hour of driving by 1.3 times the value used in the revised time-on-task (TOT) multiplier in the RIA did not make Option 1 with 10 hours driving cost effective, though it reduced the net costs from $540 million to $494 million. Nor did substantially raising the baseline level of fatigue in truck-related crashes make the 10-hour variant cost-effective; it would still show net costs of $417 million. Each change improved the showing of the 10-hour variant, but still left it with net costs rather than net benefits. Even in a very unlikely scenario that combines all three of the assumptions favorable to

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1 The reanalysis of TOT fatigue is discussed in Chapters 5 and 6 and, in more detail, in Appendix (V).

the 10-hour limit, it shows net costs of $71 million, indicating that it is implausible that eliminating the 11th hour would be cost-effective.

Exhibit ES-5 Sensitivity Analyses of Net Costs, 10-hour Driving Limit (millions of 2005$)		
	Net Costs of Option 1 w/10 hrs	
Basic Assumptions	$	540
Twice as Much Use of 11th Hour	$	1,080
Higher Value of Statistical Life (VSL)	$	432
Higher TOT Impact	$	494
Higher Baseline Fatigue	$	417
Higher VSL, TOT Impact, and Baseline Fatigue	$	71

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 HOS regulations in effect until 2003 were promulgated pursuant to the Motor Carrier Act of 1935 and codified at 49 CFR Part 395. These regulations were originally promulgated in 1937, and last revised significantly in 1962. These regulations required eight hours off between tours of duty that could be of indeterminate length, lasting until the driver accumulated 15 hours on duty. They also limited work to 60 or 70 hours in a 7 or 8 day period. Concerns that these rules were outdated and contributed to driver fatigue led to an effort to incorporate new knowledge about fatigue, rest, and their effects on safety.

The Revised Rule

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). Following reviews of the comments on the NPRM and additional study, the Federal Motor Carrier Safety Administration (FMCSA) developed a revised set of HOS regulations. The new rule was promulgated on April 28, 2003 (68 FR 22456) and took effect on January 4, 2004. A regulatory impact analysis (RIA) comparing the costs, benefits, and impacts of this rule relative to the previous rule and several alternatives was conducted in accordance with the requirements of Executive Order 12866. That RIA, which is available in the HOS rule docket, http://www.regulations.gov/fdmspublic/component/main?main=DocumentDetail&d=FMCSA-1997-2350-23302,, showed that full compliance with the new rule (the "2003 HOS rule") could both save lives and increase productivity compared to full compliance with the rule then in existence. Much of the safety advantage of the 2003 HOS rule was shown to come from the mandate for at least 10 hours off for each tour of duty, and from the contribution to keeping drivers on a regular 24-hour cycle. The contributions of the new regulations to productivity came from a provision allowing drivers to "restart" the accumulation of their 60 or 70 hours on-duty within 7 or 8 days once they took 34 hours off at one stretch.

The 2004 Appeals Court Action

After the 2003 HOS rule had been in effect for several months, it was vacated by a federal appeals court. The D.C. circuit court found, on July 16 2004, that FMCSA had not considered effects on drivers' health, and had concerns about several areas of the rule:

- Permission to drive 11 hours in a tour of duty, rather than 10;
- Allowing more hours on-duty in a given week as a result of the restart provisions;

- Allowing drivers to split their off-duty periods into two parts through the use of sleeper berths (that is, bunks within the tractor); and

- Lack of consideration of the electronic on-board recorders.

In response to the court's action, Congress extended the 2003 rule for a year, in order to give FMCSA a chance to revisit the issues cited by the court. A new HOS rule was published on August 25, 2005, retaining most of the provisions of the 2003 rule but requiring drivers using sleeper berths to spend 8 consecutive hours in the berth and take an additional 2 hours either off duty or in the berth; this 2-hour period must be counted against the 14-hour on-duty limit. The 2005 rule also provided relief to some short-haul operations using lighter trucks.

The 2007 Appeals Court Action

Public Citizen and others challenged the August 2005 rule on several grounds. On July 24, 2007, the Court ruled in favor of Public Citizen and vacated the 11-hour driving time and 34-hour restart provisions (Owner-Operator Independent Drivers Association, Inc. v. Federal Motor Carrier Safety Administration, 494 F.3d 188 (D.C. Cir. 2007). The Court vacated the rule provisions based on two arguments made by Public Citizen: that FMCSA had violated the Administrative Procedure Act (APA) requirement for notice and comment rulemaking by failing to disclose in time for comment the methodology of a model central to the Agency's justification for the rule, and, when the methodology was disclosed, FMCSA failed to provide a reasoned explanation for some of its critical elements, thus rendering the rule arbitrary and capricious.

The Court concluded that FMCSA had violated the APA's requirements by failing to provide an opportunity for public comment on the methodology of the Agency's operator-fatigue model, which FMCSA had used to assess the costs and benefits of alternative changes to the HOS rules. In particular, the Court found that the Agency had not adequately disclosed and made available for review the modifications it had made to the 2003 operator-fatigue model to account for time-on-task effects in the 2005 analysis. The Court concluded that FMCSA's methodology had not remained constant from 2003 to 2005 because the time-on-task element in the model was new and constituted the Agency's response to a defect in its previous methodology. The Court listed several elements of the way FMCSA calculated the impact of time-on-task that it held could not have been anticipated and that were not disclosed in time for public comment upon them.

The Court also found, turning to Public Citizen's second argument, that FMCSA had failed to provide an adequate explanation for certain critical elements in the model's methodology. In vacating the increase in the daily driving limit from 10 to 11 hours, the Court found arbitrary and capricious what it described as FMCSA's "complete lack of explanation for an important step in the Agency's analysis," the manner in which it had plotted crash risk as a function of time-on-task/hours of driving. The Court also found that FMCSA had failed to provide an explanation for its method for calculating risk relative to average driving hours in determining its estimate of the increased risk of driving in the 11th hour. In vacating the 34-hour restart provision, the Court found that FMCSA also had provided no explanation for the failure of its operator-fatigue model to account for cumulative fatigue due to the increased weekly driving and working hours permitted by the 34-hour restart provision.

In an order filed on September 28, 2007, the Court granted in part FMCSA's motion for a stay of the mandate. The Court directed that issuance of the mandate be withheld until December 27, 2007.

On December 17, 2007 (72 FR 71247), FMCSA published an Interim Final Rule (IFR) amending the Federal Motor Carrier Safety Regulations effective December 27, 2007, to allow CMV drivers up to 11 hours of driving time within a 14 hour, non-extendable window from the start of the workday, following 10 consecutive hours off duty. The IFR also allowed motor carriers and drivers to restart calculations of the weekly on-duty time limits after the driver has at least 34 consecutive hours off duty. The FMCSA explained that the IFR reinstating the 11-hour limit and the 34-hour restart was necessary to prevent disruption to enforcement and compliance with the HOS rules when the court's stay expired, and would ensure that a familiar and uniform set of national rules governed motor carrier transportation. The FMCSA requested public comments on all aspects of the IFR, and stated that it would issue a final rule in 2008.

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1.1 Purpose and Need for Action

The action being taken involves the FMCSA reinstating HOS regulations promulgated in the agency's 2005 HOS rule. 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 11 hours or be on duty up to 14 consecutive hours since the end of their last 10-consecutive-hour break.[2]

- Operators can cumulatively drive or be on-duty up to 60 hours over the last 7 consecutive 24-hour periods, or 70 hours over the last 8 24-hour periods.

- If a sleeper berth is used, the 10-hour break can be split into two periods of no less than 2 hours each, provided that the duty periods preceding and following each of these two periods sum to no more than 14 hours, and at least one period is at least 8 hours long.

- Operators who obtain 34 consecutive hours of off-duty time can begin a new seven-day period, over which they can 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).

[2] To be more exact, drivers cannot drive after they have been on-duty 14 cumulative hours after their last 10-consecutive-hour break.

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).

The purpose of the HOS limits is to reduce the likelihood of driver fatigue and of fatigue-related crashes. Although the rules that existed prior to 2003 allowed less daily driving than the 2003 and 2005 rules (10 hours versus 11 hours), the driving could occur 15 hours or more after the driver started working without any intervening rest, and followed a shorter minimum rest period (8 hours versus 10 hours). The change to a 14-hour consecutive duty period and a 10-hour rather than an 8-hour rest period was intended to limit the period in which a driver could operate a CMV and move the driver toward working a schedule that was consistent with the 24-hour Circadian clock that humans function on normally. The 2005 rule does not limit the number of hours a driver can perform work other than driving, but if a driver works after 14 hours, he or she must take at least 10 hours off after finishing work before driving a CMV again. The change to a 10-hour off-duty requirement also recognized that drivers need to do other things in their off-duty time besides sleeping; the 10-hour break gives them an opportunity to obtain the 7 to 8 hours of sleep most people need to be rested and to carry out other necessary day-to-day activities. The 34-hour restart provision was intended to provide drivers with an opportunity to obtain two 8-hour rest periods, which research indicates can overcome cumulative sleep deprivation. Similarly, the 2005 change to the sleeper berth provisions eliminated the practice of splitting time in the sleeper berth into increments that were too short to provide a reasonable period of sleep.

In order to avoid the huge administrative and operational burden that would be imposed on State enforcement agencies and motor carriers and drivers by the issuance of the Court's mandate at the end of December, this rule must be issued without normal notice and comment procedures. In addition, the variety of State HOS standards that would exist in the absence of this interim final rule (IFR), along with the influx of new drivers that may be needed to handle current freight volume, could have a deleterious effect on safety which would obviously be contrary to the public interest.

1.2 OPTIONS

This analysis considers and assesses the potential consequences of two potential regulatory options. Option 1 is to readopt the 2005 rule, while Option 2 is more restrictive. The options and the rationale behind their provisions are described briefly in this section.

1.2.1 Option 1

Option 1 is to readopt the 2005 HOS rule, with no additional rulemaking and no changes in the method of implementation. The FMCSA would continue to enforce the 2005 HOS regulations without change. The existing exemptions to the current HOS regulations under the NHS Act would remain in effect.

The 2005 rule 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 10 consecutive hours.

- Short-haul operators of vehicles less than 26,000 lbs GVW, remaining within a 150 mile radius of their base, may keep timecards in lieu of logbooks and may be on-duty up to 16 consecutive hours two days during a seven-day work week.

- Operators can cumulatively drive or be on-duty up to 60 hours over the last seven days or 70 hours over the last eight days.

- If a sleeper berth is used, the 10-hour break can be split into two periods of no less than 2 hours each, provided that the duty periods preceding and following each of these two periods sum to no more than 14 hours, and one period is at least 8 hours long.

- Operators who obtain 34 consecutive hours of off-duty time can begin a new seven-or eight-day period, over which they can drive or be on duty a cumulative total of 60 or 70 hours respectively (i.e., the seven- or eight-day "clock" is restarted by a 34-hour off-duty period).

1.2.2 Option 2

This option is more stringent than Option 1, and essentially keeps the most restrictive features of the pre-2003 HOS rules.

- Operators are limited to 10 (rather than 11) hours of driving within a period of 14 consecutive hours from the start of the duty tour, followed by a break of 10 consecutive hours.

- The "restart" of the 7/8 day "clock" after a 34-hour break is eliminated – as under the pre-2003 rules, operators can drive only if they have been on-duty for a cumulative total of no more than 60 or 70 hours over the last 7 or 8 days (respectively).

1.3 BASELINE FOR THE ANALYSIS

This RIA compares the costs and benefits of the options relative to the rule that is currently in force – i.e., Option 1 – and assumes that there is full compliance with each of the options. This approach ensures that the full effects of the options' provisions on costs and benefits are captured. The pre-2003 rule was not used explicitly as a baseline in this analysis because a separate regulatory impact analysis was completed that measured the economic effects between a pre-2003 baseline and the 2003 rule. However, the effects of today's options can be compared to the pre-2003 rule using the effects reported in the Regulatory Impact Analysis for Hours of Service Options (the HOS RIA) in December, 2002 (henceforth referred to as the 2003 RIA). That report, which is available at http://www.regulations.gov/fdmspublic/component/main?main=DocumentDetail&d=FMCSA-1997-2350-23302, in the HOS rule docket, assessed the effects of compliance with the 2003 rule relative to several other options. These options included a "Status Quo" option (i.e., the HOS rule that was in effect at the time of the analysis, assuming less than 100-percent compliance levels), as well as a "Current Rule/100%" option, which, similar to the current analysis, assumed full compliance with the pre-2003 rule.

1.4 Overview of the Analysis

1.4.1 Assessing Costs

The analysis of costs recognizes that the different provisions of the options will affect carrier operations in complex and interacting ways. It also recognizes that these effects will depend strongly on the carriers' baseline operating patterns, which vary widely across this diverse industry. To produce a realistic measurement of the options' impacts, then, we divided the industry into broad segments, collected information on operations within these segments, and then created a model of carrier operations as they are affected by HOS rules. Given the very wide array of operational patterns, it was necessary to limit our analysis to the most important cases.

The model was first loaded with data representative of shipping patterns and carrier cost structures, and tested to ensure that it could realistically simulate typical lengths of haul, empty mile ratios, and productivity. It was then set up to cover most important cases, under constraints representing the options, and used to simulate carrier operations under different conditions and HOS rules. We then analyzed the data representing the simulated operations, using changes in miles driven as a measure of productivity impacts. Output measures from individual runs were weighted to give a realistic representation of the affected industry, including the drivers' use of the most important provisions of the options. The weighted changes in productivity from this procedure were then used to estimate the cost increases imposed on the industry by the options, using an analysis of the changes in wages and other costs likely to result from changes in productivity. These productivity-related costs were combined with transition costs associated with shifting to new rules to produce estimates of total social costs.

1.4.2 Assessing Benefits

Safety impacts were measured by feeding the working and driving schedules from the carrier simulation model into a fatigue model to project driver effectiveness levels, and then estimating the resulting changes in crash risks under different options for different cases. Changes in fatigue-related crash risks, calibrated to match realistic levels, were then multiplied by the value of all affected crashes to yield estimates of total benefits. After several concerns with the implementation of the TOT-related fatigue analysis were noted during the appeals process, the analysis was revised and the fatigue-related crash reduction benefits were adjusted accordingly.

1.5 Remaining Sections of the Report

The remainder of this report is divided into five additional chapters. Chapter 2 profiles the affected industry, in its qualitative characteristics and in terms of quantitative measures of firm sizes and the degree to which certain HOS provisions are currently used. Chapter 3 presents the methods used to estimate the effects of the options on industry operations, concentrating on the modeling of operational changes, and Chapter 4 then explains how these changes in operations were translated into changes in cost. Chapter 5 explains the translation of the operational changes into benefits. The results of the operational modeling, and the calculation of net costs and benefits, are presented in Chapter 6.

Appendices are provided to expand on the data sources and calculations in several areas. (These appendices have been labeled with roman numerals in parentheses to avoid confusion with the appendices to the 2003 RIA (conducted for the 2003 HOS rule). Appendix (I) supports the industry profile in Chapter 2, Appendix (II) provides more detail on the simulation modeling described in Chapter 3, Appendix (III) describes recent studies on driving and fatigue, Appendix (IV) offers a supplemental bibliography, and Appendix (V) provides more detail on the revisions to the TOT-related fatigue analysis. Finally, the 2003 RIA is another important source of background material for this document; it is available at http://www.regulations.gov/fdmspublic/component/main?main=DocumentDetail&d=FMCSA-1997-2350-23302

2. PROFILE OF THE AFFECTED INDUSTRY

2.1 OVERVIEW OF INDUSTRY SECTORS

The trucking industry is not homogeneous. Its various sectors are quite different from one another in their operating characteristics and, therefore, in the way in which they are affected by changes in HOS rules. In this section, we enumerate and describe the principal sectors and the distinctive ways in which they operate.

This section is based largely on research done for the RIA for the 2003 HOS regulations. A recent review of conditions in the industry showed that the structure of the industry has not changed significantly, though the industry's overall size has grown. Thus, this section remains in the RIA, but figures for the number of long-haul drivers were scaled up to represent current conditions (as described in Section 4.1).

2.1.1 General Description of Operations

In the following table are shown the principal sectors of the industry.

<table>
<tr><th colspan="4">Exhibit 2-1
Principal Sectors of Trucking Industry</th></tr>
<tr><th rowspan="2">Over-the-road (OTR)</th><th colspan="2">For-hire</th><th rowspan="2">Private</th></tr>
<tr><td>Truckload (TL)</td><td>Less-than-truckload (LTL)</td></tr>
<tr><th>Local</th><td colspan="3">Local operations are treated as a single sector in this analysis.</td></tr>
</table>

As the table shows, there are two main lines of division in the industry: one division is between private carriage of goods and for-hire carriage; the other is between carriage that is essentially local in character and carriage over longer distances (over-the-road (OTR)). Within OTR for-hire carriage, there is another major division—between truckload (TL) and less-than-truckload (LTL) operation. In OTR service, there are major differences among the operating characteristics of private carriage and the two types of for-hire carriage, and these differences have important implications for the effects of changes in HOS rules. In local operations, these differences, to a large degree, either disappear or cease to have much significance for HOS rules. This is why Exhibit 2-1 does not show separate sectors for local service. For reasons discussed later in this chapter, the HOS rule-change options under consideration would have limited impact on local trucking.

In the following sub-sections, we present and discuss operating practices and firm characteristics in the main sectors of OTR service; this is followed by a discussion of local service. First, however, we need further elucidation of the major sector distinctions shown in Exhibit 2-1.

OTR vs. local service

We may think of local service as movement among points within a metropolitan area, and to and from points within two or three hours' drive from that area.[3] In operational terms, one important difference between local and OTR service is the kind of work the driver does. In OTR service, driving is a driver's principal task. He will spend some time loading and unloading, and waiting to load or unload. The amount of time spent on loading and unloading will vary with length of haul, types of customers, and types of service; but the preponderance of an OTR driver's time will be used for driving.

Local drivers will spend less time driving than OTR drivers. This is partly because they make many more stops to deliver or pick up goods or packages. It is also the case that many local drivers are not carrying goods, and their primary function is to perform a service, e.g., plumbing repairs, to which driving is ancillary. For these reasons, and others discussed below, none of the rule-change options will have a noticeable effect on short-haul trucking.

For-hire vs. private carriage

For-hire trucking firms are paid by others to haul goods. Virtually all of their revenue is derived from movement of freight (including packages in some cases) or related services such as logistics management.

Private carriers are firms that manufacture or distribute goods and 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.

There are major operational differences between private and for-hire carriage; as a consequence, HOS rule changes will have different effects on these sectors. These differences will be discussed in more detail later. We should note here, however, that a major factor is the regular and repetitive character of private carriage that sets it apart from a large part of for-hire service. Regularity, or its absence, in drivers' schedules makes a significant difference in the effects of HOS rules. In general, regular operations will be less affected by the options under consideration.

TL vs. LTL service

The two principal forms of for-hire OTR service differ markedly from one another, both in the kind of service provided and in mode of operation. A truckload firm moves a full truckload of freight, for a single shipper, directly from origin to destination. The driver goes to a facility of the shipper where the truck is loaded and drives to a destination point where the truck is unloaded. From there, he proceeds to another origin point to pick up another load and continues in the same manner.

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[3] As a point of demarcation, we use an average length of haul of 150 miles to distinguish local service from OTR service.

An LTL company, by contrast, moves small shipments (typically in the range of 500 to 2,000 pounds) in a series of moves that involve both local and OTR operation. Local-service trucks pick up shipments from a number of shippers, bring them into terminals where they are consolidated into truckloads for OTR moves to other terminals, whence local-service trucks deliver individual shipments to their final destinations.

Regarding the impact of HOS rules, the major difference between for-hire TL and LTL operation is that LTL service operates on a regular basis, and most TL service does not.

Below, we present the following sub-sections on industry operations.

- TL operations
- LTL operations
- Private carriage
- Regular vs. random operation
- Team operations
- Local operations

2.1.2 Truckload Operations

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.[4] At a rough approximation, there are around 50,000 TL firms. Of these, 40,000 are very small, with five or fewer tractors.[5] This group is the owner-operators, those that are genuinely independent firms with their own customers. (There are over 300,000 owner-operators in total, but the great preponderance of them are working under lease to larger TL companies such that they are, in effect, part of the labor force of those companies and not firms seeking business for their own account.)[6]

As we see in Exhibit 2-2, small and middle-sized firms receive a very substantial share of total TL revenue. Assuming annual revenue of $125,000 per tractor, a company with 100 tractors has revenue of $12.5 million—not a large company.[7] But firms with fewer than 100 tractors have about 43 percent of sector revenue. A fleet of 500 tractors implies revenue of $62.5 million—no longer a small company but not a very large one. We see that firms with fewer than 500 tractors receive revenue of $75 billion—68 percent of total TL revenue.

[4] Operating ratio is the ratio of operating cost to operating revenue.

[5] Virtually all OTR carriage is in tractor-trailer combinations, so tractors can be a measure of TL firm size.

[6] These and other estimates of industry size, revenues, etc., are based on the 2003 RIA, Appendix A.

[7] The methods and sources underlying these estimates are presented in the 2003 RIA, Appendix A.

Exhibit 2-2 Truckload Revenue by Firm Size (in billions of dollars)		
SIZE CLASS (NUMBER OF TRACTORS)	REVENUE	PERCENT
1 TO 5	9.8	8.9%
6 TO 24	12.4	11.2%
25 TO 99	25.6	23.3%
100 TO 499	27.2	24.8%
500 AND MORE	35.0	31.9%
TOTAL	110.0	100%

Some of the operations of TL companies follow regular patterns, but some do not; we refer to the latter as "random" service. A truckload company in random service 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 crisscross the nation, taking the best loads, in a business sense, as they find them.

Above some minimum size, a TL company will have one or more people whose task is to assign loads to drivers; this is the dispatch function. The 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 independent owner-operators, companies with five or fewer tractors clearly cannot support either a sales force or 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 less formal arrangements, 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 staff groups for these functions.

Length of haul

In the TL sector, "length of haul" is the distance from the point where a driver picks up a load to the point where he delivers the load. Average length of haul affects the impact of HOS rule changes. People in the truckload business make a distinction between regional and long-haul operations. A regional move is generally one of 500 miles or less, and a company calling itself regional would have an average length of haul under 500 miles or even a maximum of 500 miles. Many in the trucking business think of regional as same-day or next-morning delivery, a maximum of 500 miles. For our analysis, we have distinguished between short-regional, long-regional, and long-haul operations. On an average length-of-haul basis, we classify TL operations as follows:

Short-haul (local)	<150 miles
Long-haul	
Short regional	150-300 miles
Long regional	300-500 miles
Long haul	>500 miles

Trucking-firm behavior varies with length of haul, and these variations affect the impact of HOS rules. A driver in a regional operation, for example, is likely to have at least one pick-up and one drop-off in every day that he works. A long-haul driver will have days with only one pick-up or drop-off and days with neither in which he only drives. This difference affects the propensity to use the 11^{th} hour. The less time a driver spends in loading and unloading, the more time he has available in the 14-hour window for driving. To the extent that he has more than ten hours available for driving, he is more likely to drive in the 11^{th} hour.

2.1.3 Less-than-truckload operations

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. 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: just under one-third of TL revenue, perhaps ten percent of TL VMT. (See Exhibit 2-4 below.)

In order to operate its business, whether regional or national, an 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 loads, and return to the terminal at the end of the day with outbound loads. These loads are moved across the dock to outbound line-haul trailers. In a regional firm, these trailers will be pulled overnight to other terminals in the firm's network 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.

For the 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 is associated with a large number of satellite terminals. Line-haul moves will often be from satellite to hub and hub to satellite. In some circumstances, a trailer may go directly from a satellite to a hub in another region. Where the line-haul is more than 500 miles, moves are frequently handled with either teams or relays.

LTL trucking operates in a scheduled and routinized manner that is utterly different from the opportunistic journeys that comprise much of the business of a TL company. Many, if not most, LTL over-the-road drivers make the same run every night, and many of them never sleep away from home.

2.1.4 Private carriage

As noted above, private carriers are firms engaged in manufacturing and distribution that choose to carry their goods themselves. They do this because they believe they need direct control of the operation to ensure that tight schedule requirements are met, because they believe customer relations are enhanced when their own employees make deliveries, or for other reasons. Whatever the reason may be, private carriers incur a cost for moving their own goods. The alternative in most cases would be for-hire truckload service; private carriage is somewhat more costly than truckload—a premium of a little more than ten percent on a truck-mile basis.[8] 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 generous 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.

It is difficult to generalize about private-carriage patterns of operation, as they have 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 random for-hire TL operations. Private carriage resembles LTL companies in this regard. 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 much less the case in LTL and private operations. Part of this stems from better pay and benefits in these latter sectors; part of this is because many of these companies either employ union drivers or must compete with employers of union drivers to obtain good drivers. But part of it is surely due to the irregular and often-shifting work times of TL operation.

Some private carriers arrange for this service 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.

2.1.5 Regular vs. Random Operations

An important aspect of trucking operations is regularity or the absence of regularity—the degree to which drivers repeat the same or similar routes and working hours over successive days and weeks. As noted earlier, a high degree of regularity tends to be the norm in private carriage and LTL firms. While this is also the case for some for-hire truckload service, a great deal of for-hire TL service is random. The distinction is important, especially for safety effects.

In random TL service, a company's trucks do not follow any fixed pattern. After a rest period at home, a driver picks up an outbound load near his home terminal and begins a road tour. Neither the driver nor the company's managers have any certain idea of where the driver will go after his first load is delivered. The company's sales force will do its best to find loads for him and keep

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

him moving profitably until he completes his road tour and comes home. Most road tours will last from one to three weeks.

The defining characteristic of regular service is that it operates on predictable schedules; both managers and drivers know, with a high degree of certainty, what they are going to be doing. Regular service entails regularly repeating patterns. These may be fixed patterns where trucks follow the same series of origin-destination (O-D) pairs in the same sequence over the same time cycle. This could also be service from one or a few fixed origin points to a limited set of destinations in which loads are not moved over the same routes in a fixed sequence, but the operation is confined to that set of origins and destinations, and loads move between every O-D pair fairly frequently.

Much of the regular service in truckload companies is the dedicated service referred to above in the discussion of private carriage; this is simply out-sourced private carriage. It is often the case with these contracts that the shipper takes direct operational control of the dedicated fleet; other arrangements are also used. There are also in place contracts which provide for regular service but do not entail dedicated vehicles.

We have information on prevalence of regular service in the TL sector; we estimate it at 40 percent of TL VMT.[9]

One might suppose that regularity in operation would allow companies to plan schedules well within the limits of the HOS rules. Our industry experts[10] suggested that this is not necessarily the case; large customers may insist on schedules that leave little margin for error. We used data from an FMCSA survey[11] to test this proposition by comparing on-duty hours per tour of duty between regular and random drivers. We found little difference, as seen in the following table.

Exhibit 2-3
On-duty Hours—Regular vs. Random
Percentage of Tours of Duty[12]

On-duty Hours	Regular	Random
14	3.2	2.5
13	5.6	5.4
12	12.4	13.5
11	16.3	15.3
<11	62.4	63.2

9 Details underlying estimate are in Appendix (I).

10 A group of trucking-industry experts assisted ICF in the conduct of this analysis. Their names are in Appendix (I).

11 See sub-section 2.3.1 for explanation of this and other data sources.

12 A tour of duty is the time from when a driver starts work to when he finishes work on a given day. It is the time constrained by the 14-hour rule.

2.1.6 Team Operations

Team operation occurs in all the sectors discussed above—TL, LTL, and private carriage. These operations merit separate discussion, however, because they have some distinct operating characteristics regardless of which sector they are employed in.

The obvious difference between team and solo operation is that the former has two drivers in the cab and the latter has one. A solo tractor moves, at most, ten to 11 hours per day. A team tractor moves 20 hours per day. Even with driving in the 11th hour permitted, few teams achieve more than 20 hours per day. A variety of industry sources have told us that four hours or so of break time, with the truck stopped, out of 24 hours are necessary for most people.

The team drivers get their sleep in the berth with the truck moving most of the time they are sleeping. Unlike the case in solo operation, the drivers never sleep in a motel or truck stop as long as they are out on a road tour. As a result, rules on splitting sleeper-berth time need to be examined carefully to determine whether they may have a special impact on team drivers.

By their very nature, teams are engaged in long-haul service. Further, two drivers means labor cost per mile is higher than solo operations; accordingly, companies will make every effort to keep teams moving. They will minimize waiting time for teams; not infrequently, if teams have to do loading or unloading, they will be paid by the hour for that work in addition to their per-mile payments.

Data on the extent of team use are not plentiful. In the 2003 RIA, we estimated that ten percent of OTR VMT was accounted for by teams. For this analysis, we have two additional data points on team drivers: interviews with eight TL and one LTL companies (mostly small firms) and information from a survey of its members done by the Owner Operator Independent Drivers Association. In the latter, 6.7 percent of drivers reported themselves as team members.[13] In the nine interviews, firms reported an average of 13.0 percent of drivers as team drivers.[14] Other anecdotal evidence suggests team drivers represent over ten percent of the driver workforce for the larger TL companies. For this analysis, we have assumed that 9.0 percent of VMT is accounted for by teams.

2.1.7 Local Operations

In general, short-haul trucking work has far 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. Most of the work is regular in character; drivers go basically to the same places and do the same things every day. The HOS rule changes now under consideration are likely to have little effect on such operations.

[13] E-mail from John Siebert, OOIDA, May 11, 2005.

[14] Interviews conducted by George Edwards, one of the ICF team of industry experts.

2.2 SIZES OF SECTORS

The following table shows our estimates of VMT and revenue for the principal sectors of the trucking industry. The VMT numbers give some sense of the relative scale of operations in these sectors. In both short-haul and long-haul operations, private carriage is the largest single sector, and private carriage dominates short-haul service.

Exhibit 2-4
OTR Revenue and VMT by Industry Sector

	Random TL	Regular TL	LTL	Private
Revenue (billions 2002$)	$58	$39	$27	$123
VMT (billions)	46	31	8	81

NOTE: These estimates are from the 2003 RIA, Exhibit 3-1, p. 3-2. The only change is that truckload has been divided into regular and random service. Revenue figures for private carriage are imputed. Full details on sources and calculations are in the 2003 RIA, Appendix A, pp. A-9-11.

2.3 WORK PATTERNS

In the following sub-sections, we examine patterns of working by drivers in the different sectors of the trucking industry. In particular, we are interested in intensity of effort; this may be thought of as the degree to which drivers work close to the limits imposed by the HOS rules. We can look at this in terms of hours worked (on-duty hours) in a week and in a day, hours driven in a day, days worked and days off in a week. These measures are important for analysis of both productivity and safety effects of rule changes. In developing values for these measures, primary emphasis was placed on OTR service. Some comparable data for short-haul operations are reported in a separate sub-section.

2.3.1 Data sources

The measures of work patterns and intensity presented in this section are based on several principal data sources. For the most part, these sources provide information on for-hire TL, OTR operations. We have four sets of data on current experience (under the 2003 HOS rule): data provided by Schneider National on some aspects of its operations; data from the Owner Operator Independent Drivers Association (OOIDA) based on a survey of its members; a survey of private carriers carried out by Professor Stephen Burks of the University of Minnesota; and data collected by FMCSA (the "field survey"). The Schneider, OOIDA, and Burks data were gathered with the express purpose of obtaining information on use of three aspects of the new rule: the 11^{th} hour, restarts, and split sleeper periods.

Each of these sources is focused on a different sector of the industry. Schneider's data are about a large TL firm. OOIDA data are based on owner-operators and a small number of company drivers for TL firms. The field-survey data largely represent company drivers with small TL companies. In terms of distribution of company size, this makes sense; the great preponderance of TL companies are quite small. In the field survey, 86 percent of for-hire, TL/OTR companies have fewer than 25 tractors. In FMCSA's profile of the industry in the 2003 RIA, we estimated that 87 percent of such companies had fewer than 25 tractors. But these small companies account for a fairly small share of TL/OTR VMT—17.0 percent.[15] Viewed in terms of truckload company size, the field survey is a representative sample, but these companies account for a small share of total trucking activity. LTL firms and private carriers are sparsely represented in the field survey. Following is some more specific information on each of these sources.

Schneider

These data cover approximately 16,000 drivers. They were taken from company records for August and October of 2004.

OOIDA

OOIDA posted a survey form on its website asking drivers for information on use of the new-rule features in the month of June 2004. The data used here are based on responses from 1,223 drivers.

Burks

Professor Burks mailed a survey form to private carriers asking for information on their drivers' use of the new-rule features in the month of June 2004. He received usable responses from 29 firms covering 3,311 drivers.

FMCSA Field Survey

These data, based on drivers' log books, were obtained from companies in the course of compliance reviews or safety audits. Data cover 542 drivers with 269 firms in the period July 2004 to January 2005. For each driver, data for one month of operation were collected.

In addition to the above data, George Edwards, a member of our team of industry experts, interviewed a number of trucking firms. Information from nine of his interviews was used here; these were eight small TL firms and one small LTL firm.

2.3.2 Average hours per day—on-duty and driving

Two basic measures of work are daily hours of driving and total work, the latter term including all on-duty time, both driving and other work. The field survey and the Schneider data provide information on driving time per tour; only the field survey provides data on on-duty hours per tour. The field survey provides some information on local drivers; the Schneider data do not distinguish between local and OTR operations.

A basic assumption in the calculation is that a day is equivalent to a tour of duty. While there are exceptions, the great preponderance of drivers work one shift in a day. A tour of duty comprises the time from the driver's start of work to end of work, including driving, other on-duty, and off-duty time. Results are in Exhibit 2-5. As seen in this exhibit, the estimates of average driving hours for Schneider and OTR drivers from the field survey are quite close. As such, this raises

[15] Calculation from data in ICF, 2003 RIA, Appendix A, Exhibit A-2.

our confidence in the numbers, even though the Schneider data include local service as well as OTR drivers.

Exhibit 2-5 Daily driving and on-duty hours—averages		
	Field Survey	**Schneider**
Driving	7.7	7.6
On-duty	9.2	N/A

NOTE: The field survey is our only source for on-duty hours in tours of duty.

2.3.3 Average hours and days of work per week

For OTR drivers, a typical measure of work is number of hours in eight days; that tells us how close drivers work to the 70-hour limit for eight days. A more complete understanding of drivers' work patterns, though, is revealed by examining data on days worked per week. We can calculate this latter measure from both the field survey and the Schneider data.

Both sources give us hours worked in eight days—62 hours for Schneider drivers, 59 hours for field-survey drivers.[16] Some intermediate steps are required to convert these numbers to days per week. We divide them by 9.2 (the field-survey figure for on-duty hours per tour of duty) to obtain days worked per eight days and then make a further adjustment to obtain days worked per seven days. These results are presented in Exhibit 2-6.

Exhibit 2-6 Average Weekly Hours and Days Worked		
	Field Survey	**Schneider**
On-duty hours/8 days	59	62
Days worked per week	5.6	5.9

2.3.4 Degree of intensity of effort

Were we to look only at the averages shown above for hours of driving and hours and days of work, we might conclude that all drivers work well within the limits imposed by the HOS rules (not allowing for non-compliance). This is, of course, not the case; many drivers work and drive longer hours than the averages. We need to know the percentages of drivers that work close to the limits; this information is important for estimating both productivity and safety effects of a new rule. This information is summarized in the following exhibits on daily driving and on-duty hours and on-duty hours in 8-day periods.

[16] For both data sources, we discarded all drivers with fewer than 50 hours of work in eight days on the grounds that they were not driving full-time in the period covered.

Exhibit 2-7 Driving Hours Per Tour of Duty			
Driving Hours	**Percentage of Tours**		
	Schneider	**Field Survey**	**OOIDA**
11	**10.7**	**16.2**	**28.0**
10	**15.5**	**16.1**	**N/A**
9	**16.4**	**11.2**	**N/A**
<9	**57.4**	**56.5**	**N/A**

NOTE: OOIDA data was collected on a different basis from those of the other sources. The OOIDA survey asked for frequency of use of the 11th hour but did not otherwise ask about driving hours. FMCSA calculated the OOIDA number shown here from the underlying survey data.

It is worth noting that the on-duty hours show a pattern relative to the 14-hour limit different from that of the driving hours relative to the 11-hour limit. Drivers are driving ten or more hours in more than 25.0 percent of their work days while reporting 13 or more on-duty hours for only 8.0 percent of days. The latter number suggests that drivers are generally taking two hours of break in a 14-hour tour or their normal work shifts are shorter than 14 hours. We suspect that both are true. Inaccurate logging of on-duty hours could also be a factor.

Exhibit 2-8 On-duty Hours Per Tour of Duty (Field Survey Only)	
On-duty Hours	**Percentage of Tours**
14	**2.7**
13	**5.5**
12	**13.2**
11	**15.6**
<11	**63.0**

From Exhibits 2-8 and 2-9, we see that, while daily on-duty hours tend to “bunch” away from the limit, multi-day on-duty hours bunch close to the limit, closer, indeed, than is the case for driving hours. Exhibits 2-7 and 2-9 give us some information on differences in behavior between company drivers and owner-operators (which include leased drivers). While driving hours show a marked difference, the difference in multi-day hours is slight. Some of this could be accounted for by the fact that OOIDA’s data include some owner-operators working on their own authority; those in the Schneider data are all leased.

Exhibit 2-9 On-duty Hours in 8-day Periods			
On-duty Hours	**Percentage of 8-day Periods**		
	Schneider		**Field Survey**
	Company	**Leased**	**All TL**
>64	**41.0**	**41.3**	**26.3**
60-64	**23.5**	**25.7**	**16.6**
50-59	**35.6**	**33.1**	**57.1**

Regarding differences in the average driving hours listed in Exhibit 2-7, it should be noted that there are few owner-operators in the field-survey data; the higher percentage of 11th-hour use from the field survey, as compared with Schneider, suggests that smaller companies may push harder than larger ones, insofar as the driving limit is concerned. The OOIDA data on the 11th hour could be seen as part of such a pattern, especially if we think the own-authority owner-operators are using the 11th hour heavily. On the other hand, the multi-day hours show the reverse pattern. For 65.0 percent of reported instances, Schneider's drivers have over 59 hours; from the field survey, the comparable number is 43.0 percent. This might suggest that a big company does not schedule as close to the driving limits as a smaller company might but enjoys greater success in marketing and, thus, is able to keep its drivers moving more consistently. There could, of course, be other explanations.

In general, we must be wary of reaching too far in drawing inferences from these data. To the extent, however, that data from different sources show consistent patterns, we can use this information in our analysis with some confidence. One pattern that comes through consistently is that the preponderance of OTR drivers and trucking firms are not operating at, or close to, the HOS limits. On an approximate basis, we could say that 25 to more than 30 percent of drivers are driving more than nine hours regularly and 25 to 40 percent of drivers are regularly working more than 64 hours in eight days. Put another way, 70 to 75 percent of drivers do not go past the ninth hour and 60 to 75 percent work fewer than 65 hours in a given eight day period. The industry experts with whom we consulted throughout the study said that this is an accurate general view of industry operations.

2.4 USE OF FEATURES OF 2003 RULE

We examined the use of three aspects of the 2003 rule: restarts, the 11th hour, and the split sleeper-berth provision. The data come from the sources already mentioned: Schneider, OOIDA, Burks, and the FMCSA field survey. These sources were supplemented by anecdotal information from George Edwards's interviews and discussions with other members of our industry-expert team.

2.4.1 Restarts

All four of our data sources reported on use of restarts. OOIDA reported that almost ninety percent of drivers used the restart at least some of the time.[17] Burks reported that private carrier drivers in his survey used the restart on 61.0 percent of their runs.[18] Neither OOIDA nor Burks, however, reported on length of restarts. It soon becomes clear when looking at other data and from discussions with industry experts that, when a driver says he used the restart provision, he does not mean he took only 34 hours for the restart period. What he means is that he used the restart rule to calculate the time at which he could go back to work; drivers find the method of calculation far simpler than trying to keep track of on-duty hours in a moving eight-day period. They only have to count the hours from the last restart to know when they are approaching the

[17] John H. Siebert, "A Survey of Owner-Operators and Company Drivers on their Use of Three New 'Hours of Service Features,'" OOIDA Foundation, September 15, 2004.

[18] Stephen V. Burks, A Survey of Private Fleets on their Use of Three New 'Hours of Service Features,'" September 15, 2004

70-hour limit. Once they decide to go into restart, they only have to count the hours from that point forward to know when they may go back on duty.

Schneider and the field survey both reported relatively frequent use of restarts and gave information on the length of restarts. In Schneider's data, only 2.0 percent of restarts were taking the minimum of 34 hours. Depending on the reporting period, one-quarter to one-third of the restarts were between 34 and 44 hours. Forty-three percent were between 34 and 58 hours. Schneider showed a bi-modal distribution with peaks at 39 and 62 hours. Presumably, the former reflects cases in which the driver has taken one full day off, plus a few hours from the preceding and following days; the latter would reflect two full days off, presumably at home.

From the field survey, we see 33 percent of restarts were between 34 and 44 hours. This comports well with the Schneider data. On this basis, we can say that at least one-third of restarts are short enough to bring a productivity gain. Using the alternative method of the moving eight-day period, drivers would usually have to stay off more than 44 hours before returning to work.

Our anecdotal information on company attitudes towards restarts is that they like the provision and find some productivity gain even though drivers are staying off more than 34 hours. Managers seem hesitant to demand a return to work after 34 hours, except in unusual situations. It may, of course, be the case that taking only 34 hours off would not fit with the work schedule of many drivers, i.e., there would not be anything for them to do at the 35th hour. For example, the 35th hour might come at 3:00 AM, and the company might have no use for the driver until 8:00 AM. When a TL driver comes off his restart, his first task is to pick up a new load; the hour at which the company needs his services will be set by the requirements of the shipper of that first load.

2.4.2 Split Sleeper-berth Periods

The dominant message from the data is that most drivers never split, and those that do split do so only occasionally. Schneider's data for October 2004 show 97.0 percent of drivers never splitting and only 0.4 percent splitting "regularly." We need to bear in mind that, before the new rule, Schneider did not allow solo drivers to split at all and has only allowed them to split on an 8-and-2 basis under the new rule.

The data from OOIDA and the field survey show many more drivers splitting occasionally but few splitting frequently. We see this in the following table.

Exhibit 2-10
Incidence of Splitting of Offduty Time in Sleeper Berths

Splitting frequency	Field Survey	OOIDA
0 times per month	66%	55%
1-4 times per month	20%	20%
0-4 times per month (sum of above rows)	86%	75%
Average percent splitting per day	6%	13%

Information from the Burks survey suggests a higher percentage of frequent splitting. The Burks data are not directly comparable with those from the field survey and OOIDA. They suggest that 52.0 percent of drivers split four or fewer times a month with the rest splitting more frequently.

We think that is a correct general interpretation, but we are not sure. It is not clear why private drivers would split more frequently than others. There might be a higher percentage of teams in Burks's data; we do have evidence that teams split more frequently than solo drivers.[19]

The data in the following table come from an Insurance Institute for Highway Safety (IIHS) survey of drivers at weigh stations in Pennsylvania and Oregon and from FMCSA's Driver Fatigue, Alertness and Countermeasures Study (DFACS).

Exhibit 2-11
Incidence of Splitting of Offduty Time in Sleeper Berths —Team and Solo
(percentage of drivers who say they split sometimes)

	IIHS	DFACS
Solo	**24**	**22**
Team	**47**	**52**

Given the agreement between the IIHS and DFACS findings, we are safe in saying teams split more than solo drivers. Intuitively, that is what one would expect. There is some anecdotal evidence that the incidence of splitting by teams is higher than that found by IIHS and DFACS. A number of comments to the docket suggested higher percentages than these and also indicated that team splitting is generally balanced; that is, sleeper periods and driving stints are about equal at four to six hours each.[20] We also note that the IIHS/DFACS findings for solo drivers sometimes splitting are lower than those from OOIDA and the field survey.

What the data on splitting clearly tell us is that splitting for most solo drivers occurs on an occasional and opportunistic basis. They do not build splitting into their operating routines. When they do take a split period in the sleeper, they go right back to the ten-hour rest at the next rest period. This does suggest that most drivers find the limited rest period unsatisfactory and use it only to avoid some other problem. An unexpected period of congestion would be one example. On the other hand, routine splitting is probably part of the daily operation of many teams.

Anecdotal information from the Edwards interviews is that managers dislike splitting for solos, do not encourage it, but do not forbid it outright.

2.4.3 The 11th Hour

The following table summarizes our findings on 11th hour use.

19 There is also some ambiguity in the Burks survey which asked for the percentage of "runs" using the splitting rule but did not define runs. It appears that some respondents interpreted "run" to be a multi-day period. In the field survey data, we saw instances in which drivers reported splitting, though one of the "split" rest periods exceeded ten hours. We discarded these cases, but this shows the danger of inaccurate logging of split sleeper periods.

20 Docket 19608; see comments by Yellow-Roadway, FedEx, CR England, Overnite, ATA, MCFA.

Exhibit 2-12 Incidence of 11th Hour Use (percentage of tours or runs on which used)			
Schneider	**OOIDA**	**Field Survey**	**Burks**
10.7	**28.0**	**16.2**	**31.0**

Note: Field-survey numbers for compliant drivers only. Burks data might overstate 11th hour use because of previously noted ambiguity about meaning of "run."

These findings tell us that the 11th hour is definitely being used. As between Schneider, OOIDA, and the field survey, there is certainly an implication that big companies use it less often than small companies or owner-operators. That is plausible on the supposition that small firms push closer to the limits than large ones do. Some of the data we have adduced in this chapter certainly suggests that, though we are using data for only one large company.

In any event, in estimating overall use of the 11th hour, we have proceeded on the basis that usage is heavier for smaller firms. For this purpose, we chose to use 25 tractors as the point of demarcation between big and small truckload companies. We estimate that 40 percent of TL VMT is from small companies and 60 percent is from large companies.[21]

The high percentage for the private carriers may have several explanations. One possibility is that the 29 companies reporting are not representative. But we note that many of the responding companies have long runs; they may be building the 11th hour into their schedules. Some of the information from the Edwards interviews tells us that LTL managers are now planning some runs that use the 11th hour. This would occur, for example, when a company finds that use of the 11th hour would bring one or more additional terminals within the overnight reach of a given terminal. If LTL managers are thinking that way, one would expect to find the same thing with private-fleet managers. They, too, have systems with a fixed set of nodes (factories, warehouses, etc.); if they find that the 11th hour brings one more warehouse within a day's trip from a factory, for example, they are likely to take advantage of it.

[21] Calculation from data in ICF 2003 RIA, Appendix A, Exhibit A-2.

3. ASSESSMENT OF IMPACTS ON OPERATIONS

3.1 OVERVIEW OF ANALYSIS OF IMPACTS ON CARRIER OPERATIONS

As discussed in Chapter 2, the most important segments of the industry that will be affected by the options include solo TL for-hire drivers with random schedules, solo TL for-hire drivers with regular schedules, and solo TL private fleet drivers. Their complex patterns of operation, and the difficulty of estimating how the various provisions might interact in their effects on productivity and safety, led us to develop a simulation-based approach to analyzing these segments. We judged simulation to be more able to generate realistic combinations of behaviors than scenario-based analyses, and therefore better able to illuminate the true effects of the options.

Two other significant segments are solo LTL drivers, and team drivers. The smaller scale of the LTL segment, and the fact that its drivers tend to follow very regular schedules, led us to represent it using the results of the simulation of regular TL drivers. Because team drivers are known to be favored only in intensive long-range operations, and need to follow regular schedules, we determined that they could best be assessed using simple scenarios.

3.2 SIMULATING IMPACTS ON COMPLEX CARRIER OPERATIONS

In the simulation model used to assess impacts on the more complex types of carrier operations, a truck's progress is tracked in a computer program as the driver moves between origin and destination points, choosing new loads at the end of each run from a set of choices randomly selected from a data base representative of inter-county shipment patterns. The driver's choices are made on the basis of which loads feasibly can be picked up and delivered within specified windows, given the limits imposed by the need to stop and rest. Within feasible choices, the driver is assumed to choose (or be assigned) the load that is most advantageous in terms of its contribution to its productivity. Because the HOS rules affect which loads can be delivered, and change the amount of time that can be devoted to driving, the model is able to estimate impacts on productivity, and the accompanying changes in typical schedules.

To implement this approach, FMCSA developed an Excel macro-driven simulation model to simulate a commercial vehicle driver (CMV) operating in compliance with HOS regulations. The HOS simulation model simulates how a CMV operator would behave, starting from its home terminal and making various stops to pick up and deliver shipments over a pre-defined duration. The regulations are defined by the user so the model can analyze various types of HOS options to show a marginal impact of a specific regulation (e.g., adding one more hour to the daily limit on driving hours).

Exhibit 3-1
Operation Cycle of HOS Model

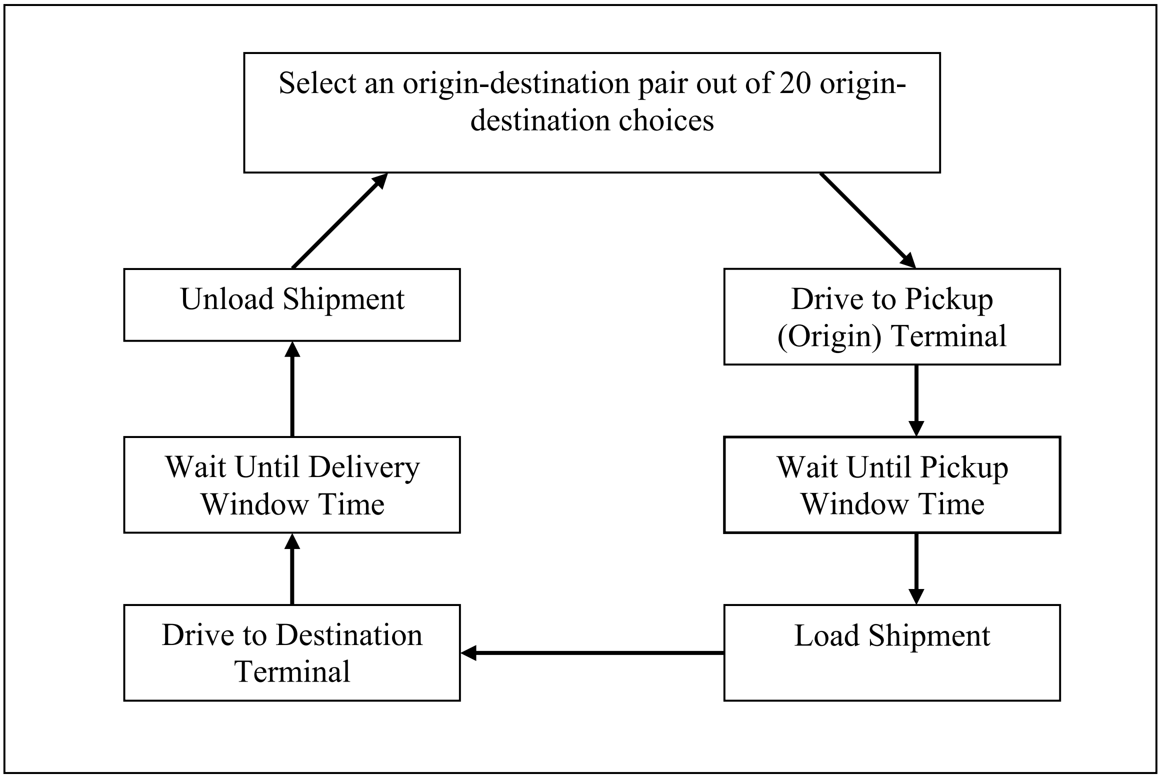

Exhibit 3-1 shows the operation cycle of the simulation model. The model starts at the user defined home terminal. Out of 20 randomly generated origin-destination pairs, it chooses the pair that best fits its schedule as well as maximizes its productivity. Then it moves to the origin terminal, waits until the pick up window time, and loads the shipment. It then drives to the destination terminal, waits until the delivery window time, and unloads the shipment. At this point, the model again analyzes another set of 20 origin-destination pairs and repeats the same procedure prescribed above for the time duration defined by the user. The movement of the truck in the model is constrained by HOS rules (i.e., all required rest periods) allowing the user to compare different facets of HOS rules with assumption of full compliance.

At the end of the simulation, the model yields an output that shows how the CMV operator behaved at each time of day. The truck's movement following the operation cycle is recorded in the schedule output table which reveals what the truck was doing at each time of the day each day during the whole simulation duration. The duration of simulation is defined by the user so the model can generate up to one year's worth of the schedule table. Exhibit 3-2 is a snapshot of the schedule table showing only a small portion of it. The table actually has over 40 columns providing details such as time of the day, day of the week, driving status, load status, origin county, destination county, cumulative duty, driving, and rest hours.

Exhibit 3-2
Schedule Output of HOS Model

Trip Day	Time of Day (24HR Format)	Day of the Week	Status	Load Status	Origin	Destn	Driving HRS Until Arrival	Load Time	Unload Time	Dummy Rest	Dummy On-duty	Dummy Driving	Cumulative On-Duty HRS	Cumulative Driving HRS
1	7.00	MON	REST	EMPTY	17,031	17,031	1.00	2.00	3.00	0	0	0	-	-
1	7.50	MON	DRIVE	EMPTY	17,031	17,031	0.50	2.00	3.00	0	1	1	0.50	0.50
1	8.00	MON	DRIVE	EMPTY	17,031	17,031	-	2.00	3.00	0	1	1	1.00	1.00
1	8.50	MON	LOAD	FULL	17,031	5,045	11.00	2.00	3.00	0	1	0	1.50	1.00
1	9.00	MON	LOAD	FULL	17,031	5,045	11.00	2.00	3.00	0	1	0	2.00	1.00
1	9.50	MON	LOAD	FULL	17,031	5,045	11.00	2.00	3.00	0	1	0	2.50	1.00
1	10.00	MON	LOAD	FULL	17,031	5,045	11.00	2.00	3.00	0	1	0	3.00	1.00
1	10.50	MON	DRIVE	FULL	17,031	5,045	10.50	2.00	3.00	0	1	1	3.50	1.50
1	11.00	MON	DRIVE	FULL	17,031	5,045	10.00	2.00	3.00	0	1	1	4.00	2.00
1	11.50	MON	DRIVE	FULL	17,031	5,045	9.50	2.00	3.00	0	1	1	4.50	2.50
1	12.00	MON	DRIVE	FULL	17,031	5,045	9.00	2.00	3.00	0	1	1	5.00	3.00
1	12.50	MON	DRIVE	FULL	17,031	5,045	8.50	2.00	3.00	0	1	1	5.50	3.50

In the following sections, more detailed description of the set-up and operation of the model is presented.

3.2.1 Assumptions

User-Defined Assumptions

In the user interface page of the model, the user defines the HOS option to be simulated. The HOS option is modeled by imposing maximum duty, maximum driving, and minimum rest hours per day, minimum restart rest hours, and maximum duty hours in the last 8 days. The model is designed to be sensitive to each of these different assumptions in order to analyze the marginal impacts of any single facet of HOS regulation under different simulation settings.

The user enters the following assumptions:

Maximum duty hours in a day

- *Maximum driving hours in a day*
- *Minimum rest hours in a day*
- *Maximum duty hours since a restart rest period in the last 8 days*
- *Minimum rest hours for a restart rest period*
- *Home terminal county*
  The county where the CMV operator's home terminal is located. The simulation starts from this county.
- *Operating region limit*
  The maximum distance the CMV operator considers for potential shipment pick-ups. For example, if the operating region limit is the default of 100 miles, the CMV

operator only considers available pick-ups from terminals located within 100 miles of its present location.

- *Minimum shipment miles*
  The minimum miles from origin to destination that the CMV operator considers for a shipment.

- *Maximum shipment miles*
  The maximum miles from origin to destination that the CMV operator considers for a shipment

- *Average speed*
  The speed of the truck during driving hours – the default is 50 mph.

- *Minimum sleeper hours*
  The minimum duration of a split rest period, using a sleeper berth. This is equal to 10 when simulating an option that does not allow any splitting of rest periods.

- *Region*
  Which of four continental U.S. regions the model will simulate: Northeast, Midwest, West, and South.[22]

- *Time increment*
  Increment of time increments, either 15 or 30 minutes, after each of which the model simulates a possible new decision and change in activity (drive, rest, load, or unload) for the CMV operator.

- *Duration for the analysis*
  The user can choose for the simulation to cover a time period of 3, 6, or 12 months.

Default Assumptions

In addition to the assumptions that can be revised by the user, the model has a number of default assumptions. These are detailed in Appendix (II), and enumerated below:

- *Loading and Unloading Time* – The time required for loading and unloading the vehicle.

- *Pick-up Day of Week* – The distribution of the day of the week for shipment pick-ups, which is that pick-up days are basically evenly distributed for the weekdays while the weekends are rarely used.

- *Delivery Day of Week* – The scheduled delivery day of the week, which depends on the pick-up day of week and the travel time required to the delivery destination.

- *Pick-up and Delivery Windows* – The pick-up and delivery windows represent the interval of time in which a pick-up or interval needs to be made

22 See Appendix (II) for a definition of the regions.

3.2.2 Model Operation

The model starts at a user-defined home terminal and selects (using a utility function[23]) the next shipment to be carried from an array of 20 randomly generated origin-destination pairs. In addition to an origin and destination, each shipment has characteristics randomly generated to simulate the pick-up terminal, destination terminal, the pick-up and delivery days of week, pick-up and delivery terminal hours of operation, and scheduled windows for pick-up and delivery.

The origin terminals are randomly drawn from the set of all terminals that are within 100 miles of the CMV operator's current location (the home terminal for the first trip). The destination terminal for each origin is then randomly drawn based on recent data on the probabilities of various origin-destination pairs (a more detailed exposition is presented in section 3.2.3 Order Sets). The seven origin-destination pairs with the earliest feasible pick-up times are evaluated to choose the shipment with the highest utility.[24]

The model runs a simulation of each of the seven O-D pairs and yields schedule output for each O-D pair.[25] The schedule output shows how the CMV operator would behave in each 15 or 30-minute time increment (whether the driver drives, rests, loads, or unloads), until the vehicle arrives at the destination. By listing the CMV operator's action in each time increment, the model can analyze whether the CMV operator is able to meet the pick-up and delivery windows and how efficiently the CMV operator is moving to the destination. If it is simulated that the CMV operator cannot meet the pick-up or delivery time windows, the model designates zero utility to that particular O-D pair and moves on to simulate the next O-D pair. When the simulations for the first seven feasible pairs are done, the model selects the origin-destination pair with the highest utility and writes its schedule output to an output table that shows the CMV operator's behavior.

Once the CMV operator arrives at the destination, the process begins again as the CMV operator is presented with another 20 origin-destination pairs and the model simulates the top seven pairs again. Thus, the model repeats the process of simulating the top seven origin-destination pairs, selecting the pair with highest utility, and writing the selected O-D pair's schedule output to the output table until the duration of the output reaches the duration defined by user in the summary page.

In summary, the driver follows the pattern of operation shown in Exhibit 3-1.

3.2.3 Order Sets

The process of obtaining a representative sample of the US truck transportation industry's movements began by obtaining data sets containing the total tons shipped to and from every

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[23] A detailed exposition on the utility function, which incorporates direct and indirect economic costs and non-monetary desires, is presented in Section 3.2.4 and in Appendix (II).

[24] The model thus discards the other 13 pairs because they were infeasible or otherwise presumed to lead to lower utility. While theoretically not necessarily true, it is believed that this type of practical rule of thumb is an accurate simulation of actual CMV operator behavior.

[25] In a few cases, none of the 20 origin-destination pairs that the CMV operator faces are initially feasible. Please see the Model Operation Note in the Appendix for how this is addressed.

county in the country, sorted by FIPS code[26]. It was decided to base the sample on the total tons shipped to and from each county to best represent the number of truckload moves. The shipments to and from each county were combined to create a table relating each county to the total tons shipped associated with it. This data set provided 3,141 data points from which to create a sample. This data set was then simplified to a sample size of 1,000, to speed model computation time, using a method that insured freight movement patterns were maintained with correct geographic representation and a mix of small and large counties. Details of this method are provided in Appendix (II).

3.2.4 Utility Function

For those segments of the industry (long-haul and regional random truckload) for which the simulation selected the next shipment immediately following the completion of the previous shipment, a utility function was used to simulate the next shipment decision. The utility function was used to monetize the total value of each of the shipment alternatives available to the driver at the decision moment. The utility function included the monetary operating costs of the vehicle, labor and labor-related costs, capital costs, revenue to be earned, and monetized penalties for the driver's time and distance away from its home and the driver's status in terms of working hours remaining before fulfillment of the 70 hour work limit.

For each available alternative of a shipment from an origin "O" to a destination "D", several total utilities were calculated (and expressed in dollars), based on the different choices the driver could make regarding resting, waiting, or driving prior to actual pick-up of the shipment. The different alternative work schedules within each origin-destination shipment were compared to determine the highest utility available for a given shipment. The different alternative shipments were then compared, with the driver assigned to perform the shipment with the highest calculated utility.

The full details including the specification and cost elements of the utility function are included in Appendix (II).

3.2.5 Algorithms

In addition to the model operation components more generally described above, a number of algorithms were used to carry out some of the specific model components. These are detailed in Appendix (II), and enumerated below.

Destination Algorithm **-** The shipments' origins and destinations are based on recent empirical data regarding the actual probabilities of commercial truck movement from county to county in the continental United States.

Load Choice Algorithm **-** As explained in the operation section (3.2.2), the model allows the user to see actual behavioral pattern of the driver in each of 15 or 30 minute time slots as the vehicle hypothetically would "move" from each of seven origin terminals to their destination terminal. The algorithm also ensures the driver complies with all of the HOS regulations.

[26] FIPS codes generally represent counties, parishes or districts. The term county is used interchangeably herein to also represent FIPS code areas, parishes and districts.

***Schedule Algorithm* -** The schedule algorithm includes all the decision-making procedures within the choice algorithm. The schedule algorithm writes the selected origin-destination pair to the output table.

***Feasibility Algorithm* -** The feasibility algorithm screens out the 13 O-D pairs that would lead to the lowest utility, as well as eliminating all O-D pairs that are infeasible because of a driver's individual rest needs vis-à-vis his status in the HOS duty/rest cycle.

***Longer Restart Rest Period Algorithm* -** In actuality, many commercial truck drivers take longer restart periods than the minimum required by the 2003 HOS rule presumably in order to start their next working period in the morning or at a convenient or accustomed time. Therefore, the model reflects the longer restart rests by imposing a specific pattern of longer restart rests.

***Break Time Algorithm* -** In order to make the model more closely reflect the driving patterns of actual truck drivers, a break period of either 30 minutes or one hour is imposed whenever the CMV operator drives four straight hours with more than one hour left until the destination.

***Split Sleeper Berth* -** When the HOS option being considered allows, the model initiates the split sleeper berth algorithm whenever the CMV operator arrives at the pick-up or destination terminal and still has some time until the pick-up/delivery hour window.

3.3 SCENARIOS RUN

3.3.1 Long-haul and Regional Truckload, Random Schedule

Three basic scenarios were run with different lengths of haul:

- short-regional: minimum run: 120 miles, maximum run: 300 miles, average: 223 miles
- long-regional: minimum run: 260 miles, no maximum, average: 465 miles
- long-haul minimum run: 400 miles, no maximum, average: 708 miles

Minimum and maximum runs were imposed for the short-regional case. No maximum was imposed on the model for the long-regional and long-haul scenarios. A minimum was specified for these scenarios, and the difference in lengths of haul came from setting the long-regional and long-haul scenarios in different geographic territories.

The short and long-regional scenarios were set in the same geographic territory for the simulations run so far. 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 Cook County, Illinois. 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 Cook County, Illinois. In terms of the default regional definitions set up in the model, the short- and long-regional scenarios included the Northeast and Midwest regions and the long-haul scenario included the Midwest and West regions.

As discussed in Section 1.2, two regulatory options were assessed. Option 1 is the current HOS rule, allowing 11 hours of driving within a 14-hour tour of duty; allowing each 10-hour off-duty period to be split into two periods of at least 2 hours each with one period of at least 8 hours, provided a sleeper berth is used and certain other requirements are met; and allowing drivers to re-start their 60- or 70-hour on-duty count after 34 hours of consecutive off-duty time. We conducted simulations both allowing and disallowing sleeper berth splitting; because no options that allowed splitting of sleeper berth periods is under consideration, the only results that are being used are the ones that disallow splitting. Chapter 6 discusses how we weighted the results from each run. Additional runs were conducted for a more restrictive variant of Option 1 which allowed only 10 hours of driving within a 14-hour tour of duty. This variant is discussed in Section 6.8.1.

Option 2 does not allow more than 10 hours of driving, and does not allow restarting the 7- or 8-day duty hour clock. This option could be modeled only approximately; the modeling allowed restarting after 58 hours, but did not allow any splitting of off-duty periods. Because the differences between the modeled and the action Option 2 are both small and expected to counterbalance each other (one will overstate costs and benefits, the other will understate them) the net effect of these approximations is expected to be very small. For both options, the model is simulated with the operating region limit of 100 miles and the simulation duration is 1 year.

3.3.2 Trucks Following Regular Schedules

Four scenarios were run with the options discussed in the previous section. The first and second scenarios were for trucks following daily schedules and the third and fourth scenarios were for trucks following weekly schedules. In the first scenario, a truck works on weekdays and returns home at the end of each work day. In the second scenario, a truck works on Saturdays in addition to weekdays and returns home at the end of each work day. Similar to the first two scenarios, in the third scenario, the truck leaves home on Monday, picks up and delivers shipments on weekdays, and returns home on Friday evening to spend the weekend at home. The fourth scenario is very similar to the third scenario, but the operator returns home on Saturday and spends only Sunday at home.

The trips in the daily model have a minimum distance of 75 and maximum of 200 miles with the average of 154 miles. The trips in the weekly model have a minimum distance of 120 miles and maximum of 400 miles with an average distance of 270 miles.

For these scheduled scenarios, the simulation model was adjusted so that there would not be any waiting time at the pick-up or destination terminals. It was also assumed that there would be only 30 minutes each of loading and unloading time, since the operators are following a predictable schedule, with coordination of the shippers, receivers, and carriers. These loading and unloading times may be shorter than generally seen, but were set to allow the model to generate realistic levels of use of the 11th hour of driving (which is usable only for drivers with relatively little loading, unloading, and waiting time in a 14-hour duty period). These scenarios were also run with the operating region limit of 100 miles and the simulation duration of 1 year.

4. COST OF CHANGES IN OPERATIONS

This chapter presents the approach to estimating the costs of the changes in productivity described in Chapter 3. The methodology used in estimating the costs in this study follow the same procedures used in the Regulatory Impact Analyses (RIA) conducted for the 2003 and 2005 HOS rules. As a result, this chapter first presents an overview of the methodology used in the 2003 RIA and summarizes the important cost estimates used in this analysis. This is followed by a discussion on the additional cost components expected to have a small impact on the total costs of the rule options.

4.1 COST COMPONENTS FROM PREVIOUS RIA

The analysis considered two main types of costs – employment costs for hiring new drivers due to the loss in productivity for the existing drivers and costs for purchasing new tractor-trailers and other support services for the new drivers. This section provides a summary of these costs. For more details about the methodology, refer to chapter 6 of the 2003 RIA.

4.1.1 Driver Labor Costs

A significant portion of the cost was estimated to be driver-related labor cost changes. Changes in the number of hours drivers can work or drive under the different HOS rule options were first translated to changes in driver's labor productivities using the simulation model explained elsewhere in this RIA. These changes were then used to calculate changes in the number of drivers needed over the baseline. We assumed 1.5 million drivers in long-haul (LH) operations based on the industry profile presented in chapter 3 of the 2003 RIA, which has been updated to 1.632 million to account for growth in the population of LH drivers since that RIA was prepared.

Changes in the number of drivers were then translated into labor cost changes using the estimated wage-hours worked functional relationship for truck drivers. This functional relationship was estimated based on an ordinary least squares (OLS) regression model expressing truck driver wages as a function of various job attributes (e.g., hours worked per week, occupational experience, and their squared terms) and other worker characteristics (e.g., age, educational level attained, marital status, sex, etc). We used data from the Bureau of Labor Statistics Current Population Survey to estimate the wage equation for the non-union segment of the trucking industry. Refer to Exhibit 6-1 in the 2003 RIA for the estimated coefficients and other details about the regression results.

Based on the regression results, we estimated the predicted wages for truck drivers for different weekly work schedules and the average and marginal wage relationships as a function of hours worked. These relationships were then used to calculate both the additional wage costs (savings) for the *existing* drivers as they were allowed to drive more (fewer) hours under the different HOS rule options, as well as the incremental wage costs for the *new* drivers required under the different options (or cost savings if there was an increase in labor productivity under an option). The wages required for drivers under the different options were also determined by the elasticity of the market labor supply curve for all truck drivers. Based on an extensive review of the labor economics literature for blue collar workers, in general, and truck drivers, in particular, we estimated the elasticity of market labor supply curve to be 5 and used it in conjunction with the average and marginal wage curves to estimate the overall labor costs for the different rule options.

4.1.2 Other Non-driver Costs

Another part of the direct costs were related to the non-driver changes necessary as a result of the changes in the number of drivers. Several categories of non-driver costs were estimated. More details about these are provided in Sections 6.4 and 6.6 in the 2003 RIA:

- **Non-driver Labor** – Costs associated with overhead labor categories that are directly proportional to the number of drivers (e.g., driver managers, load planners, etc.) Thus, hiring more drivers for the 2003 HOS options implied there was a need to hire more overhead labor, leading to non-driver labor costs. We assumed companies spent an additional 4 percent of their total labor cost calculated above on these overhead labor categories.

- **Trucks** – Costs associated with purchasing tractors and trailers for the new drivers.

- **Parking** – Construction and maintenance costs for providing additional parking spaces at terminals.

- **Insurance** – Additional tractor-trailers represent increased capital stock with associated insurance costs (even if firm-level VMT is assumed to be constant).

- **Maintenance** – Additional tractor-trailers also require increased maintenance costs for regular safety inspections and other routine maintenance requirements.

- **Recruitment** – Costs associated with recruiting new drivers.

Using the driver labor and other non-driver cost components, the total cost of the FMCSA option (i.e., 2003 rule) for the long-haul was estimated to be a cost savings of a little over $1 billion for a 3.9 percent increase in driver labor productivity (2000$). See Exhibit 9-2 in the 2003 RIA for the breakdown of this total cost into the different components. This implied that a 1 percent change in labor productivity translated to approximately $275 million (2000$) in incremental *unit* costs.

For the present analysis, we updated this unit cost to 2005$ based on GDP deflator data from the Bureau of Economic Analysis' National Income and Product Accounts (NIPA), presented in Exhibit 4-1 below.

Exhibit 4-1: GDP Deflator - (Base Year 2000=100)	
Year	**GDP Deflator**
2000	100.00
2001	102.40
2002	104.19
2003	106.40
2004	109.46
2005	113.00
2006	116.57
2007	119.66

Source: U.S. Department of Commerce, Bureau of Economic Analysis, National Income and Product Accounts Table, Table 1.1.9. Implicit Price Deflators for Gross Domestic Product, accessed May 6, 2008.

Thus, a 1 percent change in labor productivity for truck drivers translated to $298 million (2004$) in incremental unit costs for a population of 1.5 million LH drivers. Note that converting the total cost changes to a "unit cost" number, as is done here, is possible because our analysis showed that there was a linear relationship between changes in driver labor productivity and the associated costs.

The analysis for the population we are updating was conducted in 2002 for the 2003 rule, and used industry population data circa 2000. In updating the 2002 analysis in 2008, we need to reflect six years of growth. Data from BLS show that the population of production workers in the long-distance trucking industry (for-hire LTL and TL combined, but excluding private fleets which are included in the industries that operate them) increased from 629.1 thousand in 2000 to 684.7 thousand in 2006, which is an increase of 8.8 percent.[27]

Exhibit 4-2 below presents the breakdown of these unit costs into the different components discussed above as calculated for the 2005 RIA, and then as updated for industry growth and inflation. We have assumed that this same growth rate can be applied to the LH segment as a whole, and thus have raised our previous estimate of 1.5 million drivers to 1.088 times 1.5 million, or 1.632 million.

[27] Bureau of Labor Statistics, Employment, Hours, and Earnings from the Current Employment Statistics survey (National): Industry : General freight trucking, long-distance NAICS Code : 48412, Data Type : Production Workers, thousands; accessed May 9, 2008.

Exhibit 4-2: Unit Costs for HOS Options			
	From 2005 RIA	With Industry Growth	
	2004$	2004$	2005$
Change in Labor Demand	1%	1%	1%
Change in Number of Drivers	15,000	16,320	16,320
Driver Labor Cost	**$176**	**$191**	**$198**
Avoided Labor Wages	-$429	($467)	($482)
Avoided Labor Benefits	-$26	($28)	($29)
New Labor Wages	$482	$524	$541
New Labor Benefits	$149	$162	$167
Other Costs	**$121**	**$132**	**$136**
Non-driver Labor	$7	$8	$8
Trucks	$50	$54	$56
Parking	$15	$16	$17
Insurance	$11	$12	$12
Maintenance	$19	$21	$21
Recruitment	$20	$22	$22
Total	**$298**	**$324**	**$335**

4.2 ADDITIONAL COST COMPONENTS

4.2.1 Training Costs for HOS Options

The 2005 HOS RIA considered the costs of retraining drivers to comply with changes in the rules, and concluded that the annual costs would be $21 million for the LH segment. However, this retraining has, by now, already taken place for Option 1. Additionally, for Option 2, while $21 million in retraining costs is not inconsequential to those who are responsible for funding such activities, FMCSA assumes that these retraining costs would not be significant in the context of the more than $2.4 billion in total annual costs associated with Option 2.

4.2.2 Mode Shifts

As discussed above, restricting the hours truck drivers are allowed to drive (and work) reduces their productivity, thus requiring more drivers to maintain the same volume of business. Not only does this entail having to pay *all* drivers higher market wages to attract more drivers, this also means companies need additional equipment and non-driver labor. All this translates to higher costs for trucking companies and assuming a complete pass-through, implies higher rates for trucking as a result of the new options being considered. Higher rates for trucking would be expected to cause some shifting of freight from trucks to rail, which would in turn reduce the use of trucks in LH operations and reduce crash risks. Previous analysis (described in the 2003 HOS

RIA) showed this effect to be small and virtually cancelled out by the need for new and inexperienced drivers when productivity is reduced.[28] Because the net effects of the mode shift and changes in numbers of drivers are so small, neither has been considered for this analysis.

[28] As shown in Exhibits 9-8 and 9-9, on p. 9-6 of the 2003 RIA, the effects of the mode shift and inexperienced drivers are almost equal in magnitude and opposite in sign.

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5. ANALYSIS OF CHANGES IN CRASHES

5.1 INTRODUCTION AND PRIOR ANALYSIS

The safety effects of alternative changes from the long-standing HOS regulations in place prior to 2003 were analyzed in the 2003 RIA. The key features of the analysis approach are described in the following sections.

5.1.1 Literature Search and Model Selection

The analysis started with a comprehensive review of the literature relating to operator cognitive fatigue, effects of sleep deprivation and related issues. The review identified three main factors determining a truck drivers' ability to perform his or her task safely at any point during the work shift.

Circadian cycle effects. People experience a normal cycle in attentiveness and sleepiness through the 24-hour day. People having a conventional sleep pattern (sleeping for 7 or 8 hours overnight) experience maximum sleepiness in the early hours of the morning and a lesser low in the early afternoon. In addition to reduced attentiveness during the low points of the cycle, people find it difficult to sleep soundly during high-attentiveness periods. The cycle is anchored in part by the natural sunlight and darkness cycle and in part by an individual's externally imposed pattern of sleep and waking times. It follows that the performance of night shift workers is always somewhat reduced, because the influence of the natural day-night cycle on the circadian rhythm is not fully displaced by the night-work routine. In addition, circadian rhythms are persistent, and can only be shifted by 1 to 2 hours forward or backward per day by externally imposed changes in work/sleep routines and travel across time zones. Thus, changing the starting time of a work shift by more than these amounts, or the first night shift after a "weekend" break during which conventional sleep times were followed, will also reduce attentiveness.

Sleep deprivation and cumulative fatigue effects. Individuals who fail to have an adequate period of sleep (7-8 hours in 24 hours) or who have been awake longer than the conventional 16-17 hours will suffer sleep deprivation, leading to reduced performance. The deprivation accumulates with successive sleep-deprived days and is superimposed on circadian rhythm effects. Additional sleep deficits may be caused by breaking daily sleep into two shorter periods in place of a single unbroken period of sleep. Finally, unimpaired performance is not restored instantly after resuming a conventional sleep schedule, but may take two or three such sleep cycles to reach normal performance.

Industrial or 'time-on-task" fatigue. This is fatigue that accumulated during the working period, and affects performance at different times during the shift. Generally speaking, performance declines with time-on-task, gradually during the first few hours and more steeply toward the end of a long period at work. Some studies also show reduced performance in the first hour of work as the individual makes the transition from off-duty activities.

5.1.2 Effects of Work and Sleep Schedules on Driver Performance

After reviewing multiple research studies on individual aspects of sleep and fatigue, and the limited number of efforts to integrate the available knowledge into an operator performance model for individuals performing repetitive cognitive tasks, a slightly modified version of the Walter Reed Sleep and Performance Model was selected for the analysis. The model does not include time-on-task effects, and the literature review failed to yield adequate quantitative information on performance in the last hour or two of a full-length 10 or 11 hour shift. Thus the analysis did not include 'time-on-task' effects.

The inputs to this model were representative truck driver schedules developed from a variety of industry surveys and similar sources. Separate schedules were developed for long and short-haul trucking and for multiple operating patterns within each of these broad categories. The metric used to quantify driver performance in the sleep model output was the response time score on the Psychomotor Vigilance Test (PVT), which has been widely used to measure behavioral alertness in a variety of settings. Past research and testing has established the relationships between the PVT scores and sleep histories to provide the core data that drives the model.

This risk model calculates PVT for each 15 minute period during which the operator is driving. These results are used to develop estimates of truck crash risk as described in Section 5.3.

5.1.3 Relationship Between Fatigue and Motor Carrier Crashes

The first step in the analysis is to develop a relationship between PVT values as calculated by the sleep and performance model and performance in the specific task of driving a truck. This was accomplished through a series of tests on a truck driving simulator with volunteer drivers who had been exposed to different sleep and waking routines. Output from the test program was used to develop a spreadsheet model to convert PVT scores into a crash risk increment relative to a fully rested driver. The individual 15-minute crash risk increments calculated from fatigue model outputs were then combined to obtain average crash risk increments for each overall schedule and a weighted average for all long and short-haul schedules.[29]

Finally, the crash risk increments derived from the fatigue model and simulator tests were calibrated against actual truck crash risk data to project the changes in crash risk based on alternative HOS requirements. The first step in this analysis was to estimate the fraction of crashes that appear to be attributable to fatigue. After reviewing the available data, the data from a Fatality Analysis Reporting System (FARS) maintained by the National Highway Traffic Safety Administration was found to be the most credible, although it obviously does not include data on crashes without fatalities but with injuries or property damage. The FARS database provides consistent data on the causes of crashes, while other highway crash databases (such as NHTSA's General Estimates System (GES) and the FMCSA Motor Carrier Management Information System (MCMIS)) contain only limited cause data. In particular, reporting practices varied by state, and data were often missing.

[29] Note that the most complete discussion of the analysis process, including the key step of establishing the relationships between driver schedules, the PVT score and crash risk are provided in Appendix G of the original report.

The FARS data was edited to eliminate records on individual crashes where key data were missing, and also where primary fault appeared to lie with other vehicles (not trucks) involved in the crash, and with certain hazardous weather conditions. The net result of this review was that the percentage of all truck-involved crashes where driver fatigue was a factor was 7.25%, taking an average of four years 1997-2000. In addition, there is evidence that a portion of crashes where inattention is cited as a cause were also due to fatigue. Twenty percent of inattention crashes (0.89% of all crashes) was added to the 7.25%, yielding a final estimate of 8.15% for fatigue-caused crashes. As described in detail in the RIA for the 2003 HOS regulations, this percentage was projected to be reduced after implementation of the 2003 HOS regulations, to 7% for long-haul, and 3.5% for short-haul crashes[30].

5.1.4 Inexperienced Driver Effects

The 2003 RIA analysis concluded with a discussion of how the different HOS options outlined in the 2003 RIA would affect driver turnover and the need to recruit new and potentially inexperienced drivers into the industry. Research has shown that inexperienced drivers are at higher risk for a crash. The analysis concluded that there were differences in driver populations between the HOS scenarios, but that the differences were relatively small. Because of the small differences and the likelihood that the adverse effects of bringing new drivers into the industry would be offset by slight reductions in VMT (due to mode shift), the inexperienced driver analysis was not reconsidered in the current analysis.

5.2 Research Background on the Safety Effects

New information relevant to the effects of varying work/rest schedules and maximum driving time for truck drivers has become available in the period since completion of the 2003 analysis. This research has enabled refinements in the analysis of the safety effects of driving time and work/rest patterns. Most importantly, with this information, we have attempted to produce an estimate of the safety effects of varying maximum driving time between 10 and 11 hours. Incorporation of this analysis into the RIA is in response to concerns raised by the U.S. Court of Appeals in its dicta regarding maximum allowable daily driving time.

To provide a basis for the revised analyses, FMCSA initiated a supplementary search of the relevant literature. This search was supplemented by supporting analyses of data emerging from current research, including data from the Trucks Involved in Fatal Accidents (TIFA) database. Key points from the literature search as they relate to time-on-task effects, effects of short work/rest cycles, and driver performance/crash risk modeling are discussed below. Further details on the literature search are provided in Appendix (III).

5.2.1 Time-on-Task Effects

The analysis of time-on-task (TOT) effects in the safety analysis relied primarily on recent data from two research efforts, one by Ken Campbell of Oak Ridge National Laboratory, and one by a

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30 Exhibit 8-9, p. 8-32 of the RIA for the 2003 HOS rules. Note that less than half of truck-involved crashes are the responsibility of the truck driver – the remainder are due to the actions of other vehicles involved, primarily private automobiles and light trucks. This means that fatigue is a significant factor in a much larger fraction of all truck-involved crashes where the truck driver is responsible.

team led by Dr. Paul Jovanis at Pennsylvania State University. Both efforts were undertaken specifically for FMCSA, so this review relies on interim reports and other material provided to FMCSA (as identified in the footnotes) rather than formal final reports or published papers. As such, they were thought to be the most appropriate of the limited data currently available to analyze TOT effects as part of this analysis. While recent, research findings by Hanowski [Hanowski, R.J., *et al*. (2005)] for FMCSA were also considered, the Hanowski work was not thought to be appropriate for this particular (TOT-related) analysis, since it limited its examination of commercial driver fatigue and performance to the 10th and 11th hours of driving. Despite the fact that the Campbell and Jovanis studies were still in progress at the time of the 2005 analysis, these studies do consider fatigue-related crash risk across the spectrum of driving hours (at least hours one through 11) and, given that research and data of this type are relatively limited, they were considered for the TOT analysis conducted here. More recent reviews of completed versions of these studies have not shown them to be inconsistent with the functions used by FMCSA.

The Campbell analysis[31] published in the 2005 HOS rule docket used national level data from the TIFA database for the years 1991-2002, comprising over 50,000 truck-involved crashes. This database was developed from truck crashes in the NHTSA FARS database, with additional data on the driver and the carrier involved, compiled by the University of Michigan Transportation Research Institute (UMTRI) after FARS data are published. Most importantly, UMTRI added data on time since the driver's last 8-hour break, the truck and carrier types, and the planned trip length to the FARS data to create the TIFA database. Note that, because this data collection effort predated the 2003 rule change, the results reflect pre-2003 HOS regulations: driving time was limited to 10 hours, the minimum rest time between trips was only 8 hours, and there were no provisions for a restart of the cumulative 7/8 day duty period. Also, the data do not include any information on the driver schedule over a longer period than the shift in which the crash took place. Thus, it is not possible to determine if cumulative fatigue may have been a factor.

The Campbell analysis addressed several aspects of the effect of driver fatigue on crash risk, including the fraction of crashes where fatigue was reported as the leading cause in FARS, the prevalence of fatigue by motor carrier industry segment, truck type, time of day, and hours of driving at the time of the crash. For the last of these analyses, a chart was provided of relative crash risk for each successive hour of driving. Relative crash risk for each hour is calculated as a multiple of the crash risk in the first hour. Exhibit 5-1 shows the results.

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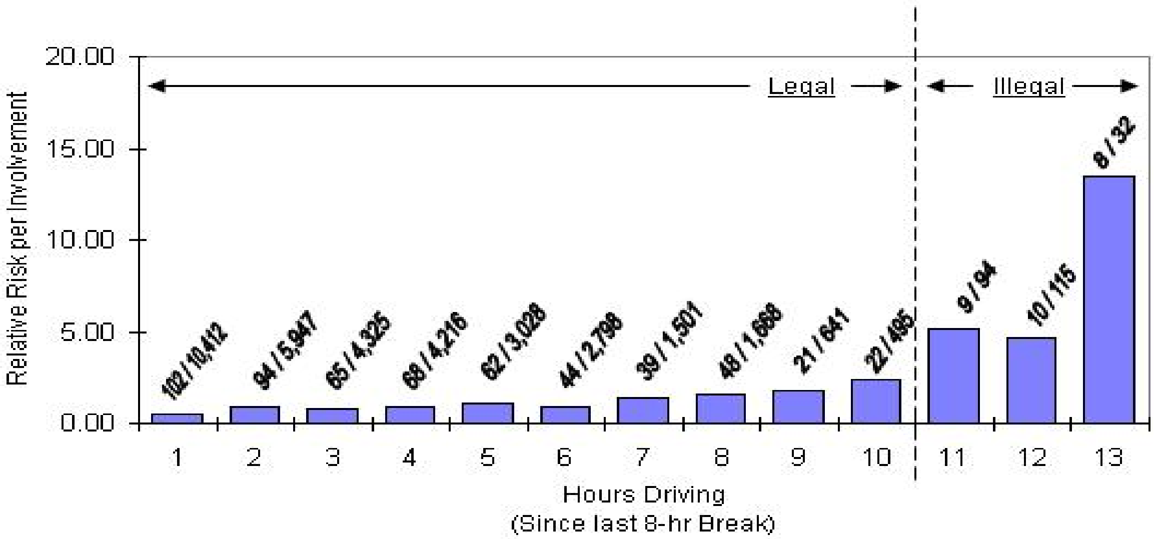
[31] Ken Campbell "Estimates of the Prevalence and Risk of Fatigue in Fatal Crashes Involving Medium/Heavy Trucks Update for 1991-2002 TIFA Files." Letter Report to FMCSA, February 25, 2005

Exhibit 5-1
Relative Risk of Fatigue Involvement by Driving Time Under the Pre-2003 HOS Rule



NOTE: Numbers above each bar chart represent the number of large trucks involved in fatigue crashes and total fatal crashes, respectively.

Data Source: Trucks Involved in Fatal Accidents (TIFA), 1991-2002

For example, for the 10th hour of driving, Exhibit 5-1 indicates that the relative risk per involvement in a fatigue-related crash is roughly 2.5 times higher than in the first hour of driving (reading across to the vertical axis of the chart). In the 11th hour of driving, the relative risk per involvement in a fatigue-related crash is roughly five times higher than that in the first hour. The first number above each bar chart represents the number of large trucks involved in *fatigue-related fatal* crashes between 1991 and 2002 for each driving hour, while the second represents the total number of large trucks involved in *all fatal* crashes within that same driving hour. For example, within the 11th hour of driving, there were 9 large trucks involved in fatigue-related fatal crashes between 1991-2002, while there were 94 large trucks involved in all fatal crashes during that same driving hour. The figures above each chart help to provide a better understanding of the prevalence of large truck fatal crashes in each driving hour, in that they reveal that as driving hours increase, the number of fatal crashes, as well as fatigue-related fatal crashes, generally decrease in a steady fashion, or in a fashion that is exactly inverse to the relative risk chart shown in Exhibit 5-1.

Using the 11th hour driving data as an example, the relative risk ratios representing each bar chart in Exhibit 5.1 were estimated via the following steps. First, the number of trucks involved in fatigue-related fatal crashes (9) within the 11th hour of driving were divided by the number of trucks involved in all fatal crashes in the 11th hour of driving (94). The result, 9.6 percent, represents the percentage of all trucks involved in fatal crashes during the 11th driving hour where it was determined that the truck driver was fatigued at the time of the crash. Second, the number of trucks involved in fatigue-related fatal crashes between 1991-2002 for *all* hours of driving (990) was divided by the number of trucks involved in all fatal crashes for all hours of driving (53,249), which yielded an overall ratio of 1.9 percent, or the percent of all large trucks involved in fatal crashes during this time period where the truck driver was determined to be fatigued at the time of the crash. Finally, to estimate the relative risk ratios that appear in Exhibit 5-1, the percent of all trucks where fatigue was present at the crash within each driving hour (i.e., 9.6 percent in the 11th driving hour) was divided by 1.9 percent, or the percent of all trucks involved in fatal crashes across all driving hours where it was determined that the truck driver was fatigued at the crash. The result is a relative risk estimate per involvement in a fatigue-related crash for each driving hour. In the case of the 11th driving hour, this estimate is equal to about five (or 9.6% divided by 1.9%), which is represented by the height of the bar chart in Exhibit 5-1 for the 11th driving hour.

There were some concerns with the TIFA data contained in Exhibit 5-1: first, there are very few crashes for drive times over 10 hours (i.e., only 9 fatigue-related crashes in the 11th hour, only 10 in the 12th hour, and only 8 in the 13th hour). Such limited populations of fatigue-related crashes raises uncertainty with regard to the relative risk ratios associated with the later driving hours, since the misclassification of a single crash as fatigue-related can affect the resulting relative risk ratios quite substantially. For instance, misclassification of a single fatal crash-involved large truck driver as fatigued in the 11th hour of driving would increase the number of trucks involved in fatigue-related crashes from 8 to 9, thereby increasing the relative risk ratio from 4.57 to 5.15, or 12.5 percent.

Other concerns with TIFA data include the fact that the pre-2003 regulations limited legal driving time to 10 hours, which meant that driving in the 11th hour was illegal at the time these data were collected. As a result, the data on the frequency of driving 11 hours or more could be underreported. As such, it is unclear whether fatigue-related crashes are over- or under-represented in the TIFA data set, since it is not possible to determine whether any under-reporting involved all fatal crashes during the 11th hour of driving, or just those where the truck driver was determined to be fatigued. Also, because driving beyond 10 hours was illegal under the pre-2003 rule (or at the time these data were collected), the relative risk of the subpopulation of commercial drivers admitting to illegal driving during the 11th hour or later may not reflect the relative risk of drivers operating legally under the 2003 rule. Unfortunately, TIFA data for calendar year 2004 (the first year when driving in the 11th hour was permissible) were not available until late 2006, and therefore could not be included in the original analysis. Given these uncertainties, FMCSA conducted a sensitivity analysis regarding the estimates used in the RIA for the relative risk of a fatigue-related crash. The results of this and other sensitivity analyses can be found in Chapter 6, Section 7, of this RIA. Additionally, updates to the original TIFA data analysis and the effects of those updates on benefit-cost results are discussed in Appendix (V).

In addition to the TIFA data, FMCSA also analyzed data from the Large Truck Crash Causation Study (LTCCS)[32]. These data covered the period from April 2001 through December 2003 and contains a sample of approximately 1,000 crashes. The result of the driving time analysis is shown in Exhibit 5-2. The overall result is similar to that derived from the TIFA data, although relative fatigue involvement factors for hours exceeding 10 hours represented by the LTCCS data appear to be lower than from TIFA data.

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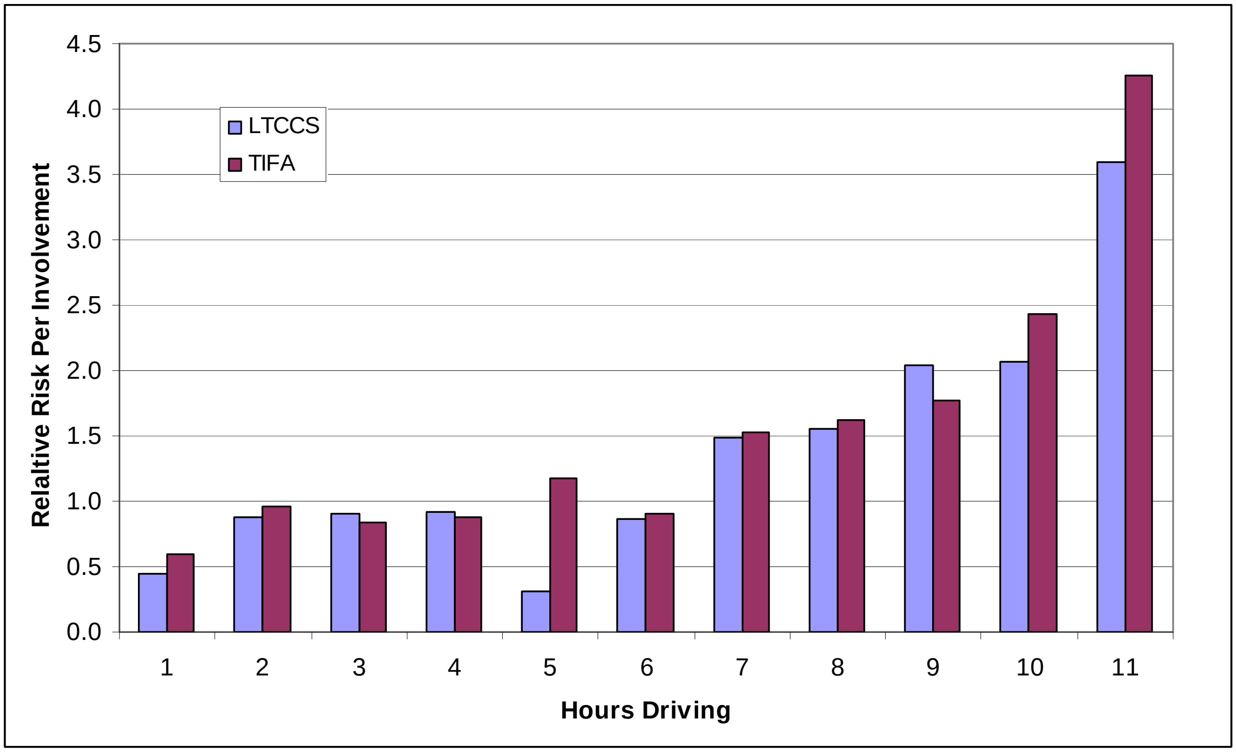
32 Large Truck Crash Causation Study Website: http://ai.fmcsa.dot.gov/ltccs/default.asp

Exhibit 5-2
Relative Risk of Fatigue Involvement by Driving Time, Comparing LTCCS and TIFA Data



In contrast to the Oak Ridge/Campbell analysis, the Penn State/Jovanis analysis relied on a sample of data obtained from three cooperating LTL carriers, as described in two interim reports to FMCSA[33],[34] The sample included seven-day driver records for 231 crashes and comparable data for 462 similar periods without a crash. The sample periods were randomly selected. All the data obtained to date are for the calendar year 2004 after the introduction of the revised HOS regulations which permitted an 11th driving hour and required longer breaks between on-duty periods. Conversely, the sample of commercial operators driving in the 11th hour is very small, with the data limited to 34 drivers. TOT task effects were calculated for the entire sample and for different subsets of the data, including operations with team drivers and sleeper berths, and different start times and shift patterns.

The primary result for all industry segments and driving routines combined is shown in Exhibit 5-3. The main limitation with this analysis is that there are very few driver cases involving 11 hours of driving (34, which includes both crash and non-crash cases). The small sample for the 11th hour presumably contributes to the low statistical significance of the results for that hour, as well as the very high variance surrounding the estimated 11th hour crash risk. The data show an 11th hour risk factor of about 3.4, which would be substantially higher than the equivalent estimates derived from the LTCCS data discussed above, though because of the uncertainty in

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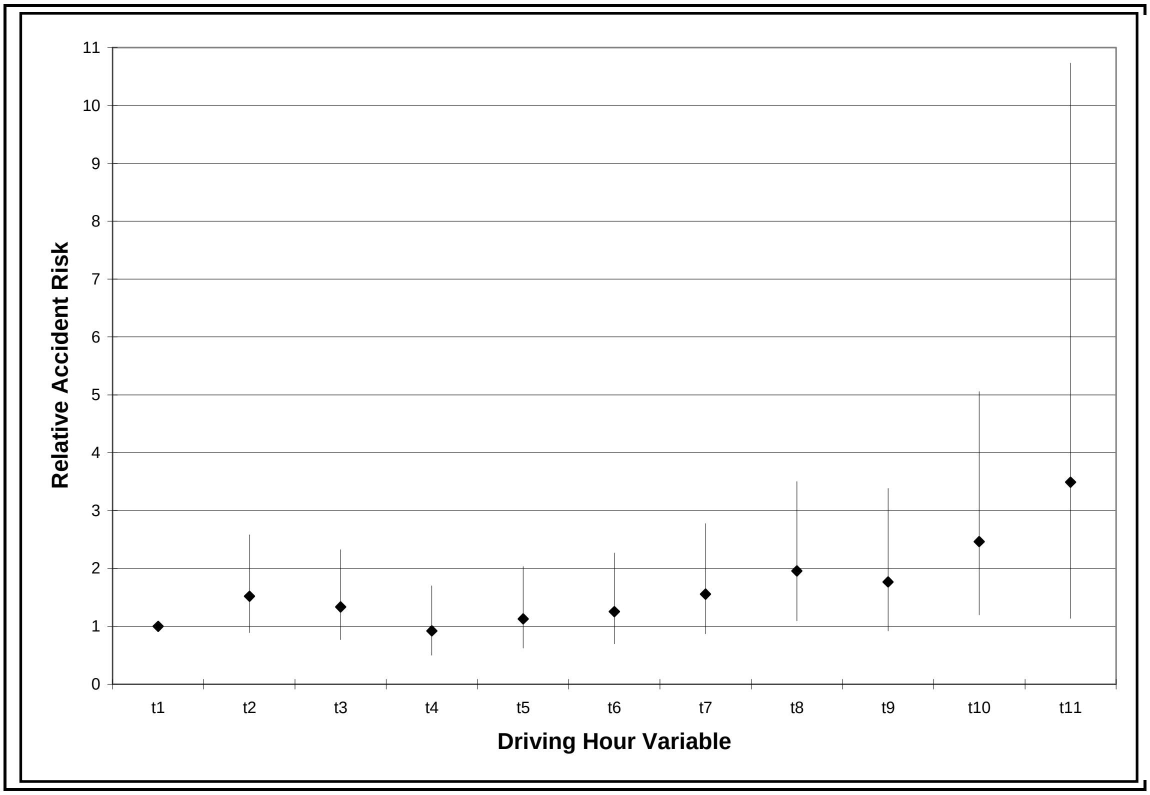
[33] Paul P. Jovannis, Sang-Woo Park, Ko-Yu Chen, "Crash Risk and Hours Driving: Interim Report" Letter report to FMCSA, Pennsylvania Transportation Institute, Penn State University, February 25, 2005

[34] Paul P. Jovannis, Sang-Woo Park, Ko-Yu Chen, "Crash Risk and Hours Driving: Interim Report II" Letter report to FMCSA, Pennsylvania Transportation Institute, Penn State University, April 15, 2005.

the results, this risk factor is not inconsistent with the LTCCS analysis. This study also had not passed peer review as of the time of the analysis of the 2007 HOS options. Jovanis also reported that the results are comparable to results obtained from a similar analysis of data gathered in the 1980s.

Exhibit 5-3
Relative Crash Risk with Driving Time
(Jovanis Sample of LTL Operation)



5.2.2 Driver Performance and Crash Risk Modeling

An evaluation of available models to calculate performance as a function of sleep and work schedules was carried out in preparation for the 2003 RIA analysis. At the time, the Sleep Performance Model (SPM) developed by the Walter Reed Army Institute of Research (USAIR) was selected as the most appropriate for this analysis. Appendix E of the 2003 RIA describes two other candidate models that were not selected. Since that time, the SPM was further refined and expanded in a cooperative effort involving multiple research organizations. The model has been adapted and applied to a number of different activities, including military operations and surface and air transportation modes. Several considerations prompted selection of the revised model for this RIA analysis:

- Use of a related model should ensure reasonable consistency with the 2003 RIA.

- A limited literature search conducted for this analysis failed to identify any comprehensive model that would be a credible candidate for this analysis, and which had not been previously evaluated.

- The model had already been adapted and used for performance analysis for different transportation operations.

- The model had been incorporated into a commercially-available software package complete with user interfaces, facilitating use of the model.

Details of the model's approach to analyzing the effects of driving schedules on driver performance is documented in a paper by Steven Hursh and his colleagues at the WRAIR, the Naval Health Research Center (NHRC) and the Air Force Research Laboratory (AFRL).[35] After moving to SAIC, Hursh developed a commercial software tool that applies the analysis methodology (called the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model) to a Fatigue Avoidance Scheduling Tool (FAST). The tool is closely related to the WRAIR SPM used in the 2003 RIA, and is continually being developed and refined as new research data has become available from WRAIR, NHRC and AFRL research programs. Further refinements to the tools were sponsored by AFRL and the US Department of Transportation in air and surface transportation activities. FMCSA applied the current commercially available version of the SAFTE/FAST tool to this analysis of variations in HOS regulations.

The core concept behind the SAFTE model is that of a sleep reservoir which individuals draw upon while awake and replenish by sleep. The overall structure of the SAFTE model is described below.

Alertness or performance is a function of three inputs:

- The amount of depletion of the sleep reservoir – research shows performance declines to the low level of 25% of that of a fully rested individual after 72 hours continuous wakefulness. A linear relationship between performance and sleep debt is used, although some research results suggest a non-linear relationship. Both the slope and shape of relationship can vary with the test task used to assess performance.

- Sleep inertia effects. Full wakefulness is not attained instantly on awaking. Instead there is a period, typically on the order of 1 to 2 hours, depending on sleep intensity and the current status of the sleep reservoir, during which performance recovers to a peak value, after which the normal decline with reservoir depletion resumes.

- Circadian rhythm effects. As discussed in Section 5.1.1, circadian cycles affect alertness as a function of time of day and the individual's sleep/waking cycles over the past several days.

[35] Steven R Hursh, Daniel P. Redmond, Michael L. Johnson, David R. Thorne, Gregory Belenky, Thomas L. Balkin, William F. Storm, James C. Miller and Douglas R. Eddy "Fatigue Models for Applied Research in Warfighting", Aviation Space and Environmental Medicine, Vol 75, Number 3 Supplement, 2004.

The model applies the results of numerous research studies of each effect to provide a continuous estimate of performance levels over time. In principle, the model is not limited to one specific performance measure (such as the Psychomotor Vigilance Test (PVT) measure used in both this and the original truck HOS analysis), provided there is a sufficient research base to establish the relationships between task performance and the status of the sleep reservoir.

Replenishment of the sleep reservoir also depends on multiple inputs, as follows:

- Length of sleep. A non-linear function exists between the length of sleep and the amount of replenishment. The per-hour replenishment is less for the first three hours of sleep than later in the sleep cycle. The model also incorporates a factor for fragmented sleep, to quantify the reduction in sleep effectiveness due to frequent wakening, such as from external noise and vibration or a sleep disorder.

- Reservoir depletion level. Generally the lower the sleep reservoir, the greater the restorative effect of sleep. The term sleep intensity is used to quantify this effect.

- Circadian rhythm. Sleep is more effective (higher sleep intensity) around the low points in the circadian rhythm.

As with performance estimates, the SAFTE model applies the results of numerous research studies to estimate reservoir replenishment for a given period of sleep.

The authors conclude by identifying a number of areas where there are unexplained contradictions or anomalies in the available data, and where further research would be useful. One key area is the relationship between the performance metric and the actual demands of a specific task. In the HOS analyses, a relationship was developed between PVT and crash risk from truck driving simulator tests. Similar relationships are needed for other tasks, both to identify the most appropriate measure for a specific task and to establish a relationship for use in practical applications of the model.

The procedures for estimating the crash increment as a function of average PVT values and then the variation in estimated fatal and non-fatal truck involved crashes due to driver fatigue effects are unchanged from the 2003 RIA analysis, except that a baseline estimated performance under the 2003 regulations is substituted for the baseline before the 2003 change.

5.2.3 Other Relevant Literature

A broader review of literature, concentrating primarily on material identified since the 2003 RIA is provided in Appendix (III). Some specific research findings of relevance to this analysis included the following:

- A detailed laboratory study by Balkin et al.[36] at the WRAIR, sponsored by FMCSA and other transportation interests, in which a sample of truck drivers with different levels of sleep deprivation operated a truck driving simulator, and were evaluated by

[36] Balkin, T, Thome, D., Sing, H., Thomas, M., Redmond, D., Wesenstein, N., Williams, J., Hall, S., and Belenky, G. "Effects of sleep Schedules on Commercial Motor Vehicle Driver Performance" FMCSA Report 2004.

the number of crashes during simulated driving and using the PVT. An associated field study used wrist actigraphy to determine sleep times and duration for a sample of long and short haul truck drivers. This study provided the key link between PVT as calculated by the SAFTE/FAST model and truck crash risk, used in this analysis (see Section 5.4.4) and also some material to support the analysis of off-duty activities as described in Section 5.4.1.

- A field study to compare driving performance and sleep patterns of team and single drivers on long, multi-day trips, sponsored by FMCSA.[37] The most interesting result from this study was that team drivers suffered fewer instances of extreme drowsiness than single drivers, in spite of short and less effective sleep periods in the truck's sleeper berth, while the truck continued traveling with the second driver. Team drivers tended to drive more conservatively than single drivers and would manage fatigue by swapping drivers when the active driver was fatigued. Single drivers tended to push on in spite of fatigue, exposing themselves to greater crash risk. This result can be contrasted with the results from the SAFTE/FAST model that showed team drivers to have a lower performance than a single driver (Section 5.4.1), primarily because the first part of a period of sleep is less effective at replenishing the sleep reservoir than the later part. At least in the observed population, the basic performance disadvantage of a typical team driving schedule was more than offset by an effective fatigue management strategy employed by the drivers. The small sample size (56 drivers, including 26 team drivers), however, and the possibility that the drivers were self-selected and therefore not necessarily representative, means that we may not be able to generalize the study's results.

- In another FMCSA-sponsored study[38], Hanowski et.al. investigated the relationships between fatigue and critical incidents, and between sleep history and fatigue for a sample of short-haul truck drivers. Key findings from the study included the following:

    - There was clear evidence of fatigue (eyelid closure) in 21% of at-fault critical incidents
    - Much variation in on-the-job sleepiness was related to off-duty sleep behavior rather than anything related to the job.
    - Critical incidents were concentrated at the beginning of the week.
- A recently published (2004) survey of truck drivers concentrating on the effects of safety management practices by the trucking firm on crashes and close calls.[39] The study was unable to establish any relationship with crashes (possibly because fewer than 10% of truck crashes are due to fatigue), but showed that good safety management had a significant effect on close calls. Good practices included regular scheduling and careful management of fatiguing loading and unloading activities.

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37 Dingus T., Neale, V., Garness, S., Hanowski., R., Keisler, A., Lee, S., Perez, M. and Robinson, J. A. "Impact of Sleeper Berth Usage on Driver Fatigue" Final Report, FCMSA-RT-02-070, 2002.

38 Hanowski, R. J., Weirwille, W. W., Gellatly, A. W., Early, N., and Dingus, T. A. 'Impact of Local Short-Haul Operations on Driver Fatigue" FMCSA Report 2000.

39 Morrow, P. C., and Crum, M. R. "Antecedents of Fatigue, Close Calls and Crashes Among Commercial Motor Vehicle Drivers" Journal of Safety Research, Vol 35, Number 1, 2004.

> The study also observed that some drivers started work fatigued, and that employers could implement policies to encourage sensible off-duty fatigue management in their employees.

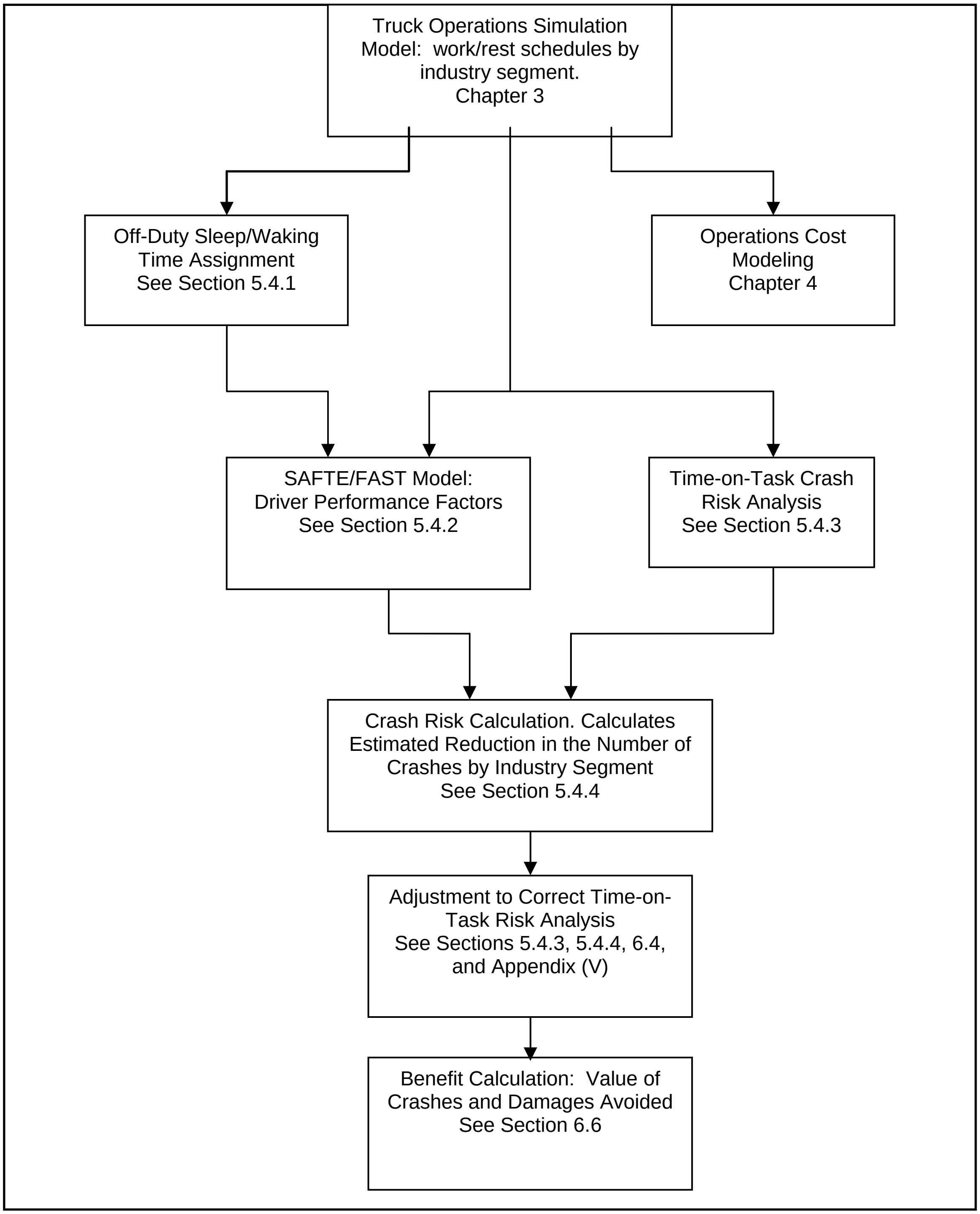
5.3 OVERVIEW OF CRASH AND BENEFIT ANALYSIS

In this analysis, the base case is the set of HOS regulations implemented in 2003, and the analysis evaluates the effects of changes from these regulations. Revisions to the 2003 RIA analysis include inclusion of TOT effects and use of the newer SAFTE/FAST model for analysis of driver performance as a function of work and rest schedules.

The overall approach to this analysis is illustrated in the flow diagram, Exhibit 5-4. The crash and benefit analyses use the output of the truck operations simulations as the starting point for the analysis. The operations analyses, described in Chapter 3, provide a series of realistic truck driver schedules for each trucking industry segment, and for each set of HOS regulations being examined in this analysis. The schedules specify driver activity for each half hour (off duty, on-duty driving, and on-duty performing other activities such as loading, unloading, and waiting) over a multi-day period. The outputs of the simulations are used as inputs into cost modeling described in Chapter 4, as well as the crash analysis described in this Chapter.

The one piece of data about driver schedules that the simulation model does not provide is how the driver splits off-duty time between sleep and other personal activities. This information is an essential input to the driver performance model described in Section 5.4.1. A separate analysis to address this question was carried out to add this information to the working schedules, based on sleep pattern surveys and similar research. These analyses led to a set of algorithms for sleep time based on the length of the break and the time of day at the start and end of the break.

Exhibit 5-4
Flow Diagram for Crash Risk Reduction and Benefit Calculations



The driver performance analysis is described in Section 5.4.2. The SAFTE/FAST human performance model, developed in part from research led by the Walter Reed Army Institute of Research, was used for the analysis. The inputs to the model were the driver schedules developed in truck operations simulations described in Chapter 3, supplemented by the analysis of driver off-duty hours described in Section 5.4.1. The model applies a large body of sleep and fatigue research, including circadian rhythms to provide an operator effectiveness percentage relative to a fully rested individual.

Because, as discussed, the SAFTE/FAST model does not take into account TOT effects, a separate analysis of these effects was performed to determine the relationship between TOT and crash risk. This relationship was applied to the driver schedules from the simulation model to estimate the effects of changing the maximum driving time from 11 hours to 10 hours. Recently, in response to issues uncovered during the 2007 Appeals Court process, the relationship between TOT and fatigue was re-estimated and its application to the data was updated. This process resulted in the application of a correction factor that raised the estimated benefits of shorter driving periods somewhat. These revisions are described in Sections 5.4.3, 5.4.4, 6.4, and Appendix (V).

5.4 DETAILED DESCRIPTION OF THE REVISED CRASH AND BENEFIT ANALYSIS

5.4.1 Off-duty Sleep Time Assignment

In order to use the SAFTE/FAST model to process the outputs of the operational model, we needed to determine how much sleep the drivers were getting and when that sleep would occur during a given off-duty period. This procedure is described below.

In the productivity analysis outlined in Chapter 3, we were concerned with the length of the driver's on-duty, off-duty, and driving periods. While the safety model requires the length of the on-duty and off-duty periods, it also requires the amount of sleep taken by the driver, and the placement of that sleep within the off-duty period. These are the two functions of the sleep allocation model. Once the driver's schedule has been separated into on-duty periods, off-duty periods and sleep periods, it is ready for input into the SAFTE/FAST model.

The first step in the sleep allocation process is to determine how much sleep a driver is expected to get based on past work history. This calculation is a decreasing function based on the cumulative amount of on-duty time in the previous 24 hour period. The basic function is identical to the one used in the 2003 RIA, which was based on statistical analysis of actigraph data on actual driver sleep from the Walter Reed field study of actual driver operations and behavior.[40] For a driver who works 14 hours a day on a continuous basis, that amounts to 6.57 hours of sleep per 24 hour period. Once the amount of sleep is determined, the model checks to see how much sleep the driver has received over the previous 24 hour period. If the driver has had more sleep than he is expected to get, a sleep surplus is assumed to exist. If the driver requires more sleep than he has received over the last 24 hours, he has a sleep deficit and the model allocates sleep until the driver's deficit has been reduced to zero or until the driver begins his next on-duty period, whichever comes first.

The second step in this process is the actual placement of the sleep within the off-duty period. To begin, the model consolidates all of the driver's sleep within a period of time. For off-duty periods less than 24 hours, it is assumed that the driver will rest in a single session, and so the sleep is consolidated into a single sleep period. For rest periods equal to or longer than 34 hours,

[40] ICF 2003 HOS RIA, pp. 8-23 and 8-24.

the driver is assumed to be taking a week-end break or restart of some length, and multiple sleep periods will be allocated based on the length of the rest period. Once the sleep has been consolidated, it needs to be placed within the off-duty period. After some test runs involving different rest period lengths and times of day, we assumed that the driver's sleep period should be placed as late in his off-duty period as possible, while still allowing him to wake up 30 minutes prior to the beginning of his next on-duty period. This 30-minute buffer was included to allow the driver to overcome any sleep inertia present when he awoke. We determined that by placing the driver's sleep towards the end of his off-duty period, it allowed him to start his on-duty period with the highest possible level of effectiveness. Whether drivers base their personal sleep allocation decisions on this same rationality is not clear at this time.

5.4.2 Modeled Impacts of Individual Schedule Factors on Performance

This section presents the results of investigations of several individual aspects of driver schedules using the SAFTE/FAST model. These investigations cover the effects of lengthening the breaks between multi-day work periods, changing the degree of regularity in schedules, and splitting rest periods into two pieces.

Impact on Driver Effectiveness of Longer Weekly Breaks

One important observation made while using the SAFTE/FAST model was the relatively small improvement in driver effectiveness when shifting from the 34-hour restart to a 58-hour restart. The small effects of longer breaks were noticed in the results of detailed modeling of large numbers of weekly schedules for drivers in various types of operations. To explore the effects of an additional day off under simplified scenarios that could isolate the effects of longer weekly breaks, we modeled two drivers on regular schedules and compared their levels of effectiveness. Both drivers had on-duty periods of 14 hours from 7 AM to 9 PM. Off-duty periods of 10 hours made up the remaining portion of the day, from 9 PM to 7 AM the following day. Those drivers with a 34-hour restart worked 6 consecutive days with 1 day off and those drivers with a 58-hour restart worked 6 consecutive days with 2 days off. Because the function used to estimate sleep for drivers is sensitive to differences in time off, the extra day off in the second scenario leads to about 1.6 extra hours of sleep, once per week. Thus, the driver with more time off can be expected to start the work week slightly more rested, and therefore with a lower crash risk. The average driver effectiveness results for the 14-hour on-duty periods are summarized in Exhibit 5-5 below.

Exhibit 5-5
Average Effectiveness during On-Duty Periods

34-Hour Restart		58 Hour-Restart	
Average Effectiveness	94.10%	Average Effectiveness	94.59%
St. Dev.	1.69	St. Dev.	1.69
Minimum Effectiveness	90.51%	Minimum Effectiveness	90.84%

Thus, an extra day off, and the slight increase in sleep it makes possible, does show an increase in average effectiveness. The change is quite small, however; less than half of one percent, which would translate into a reduction of only a quarter of one percent in crashes. The results of this illustrative example are in line with the safety model results based on the outputs from the productivity model described in Chapter 3, which were used to estimate the crash reduction benefits described in Chapter 6.

Importance of Regularity in Driver Schedules

Another observation from the results of the safety modeling was the importance of maintaining a 'regular' schedule. By 'regular', we are referring to the driver's ability to work and rest in the same general timeframe over consecutive work days. The importance of regularity stems from the effect that circadian rhythm has on driver effectiveness. Those drivers who had substantial shifts in their daily work/rest cycle performed considerably worse than those drivers that maintained a relatively constant schedule. It should also be noted that those drivers that shift to an entirely new schedule and maintain it over a period of weeks will eventually adapt to the new circadian rhythm. It is those drivers that shift to a different schedule on a daily or weekly basis that show substantial drops in effectiveness. As an example (which is merely illustrative, and was not used directly in the analysis), compare the two FAST model screen shots below.

Exhibit 5-6: Driver on a 'Regular' Schedule

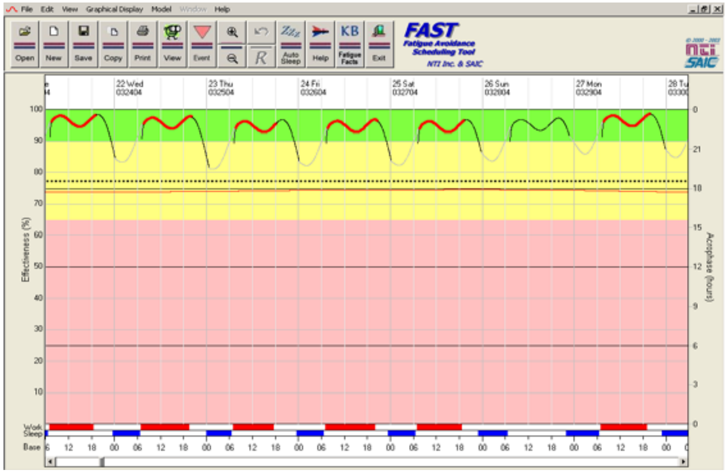
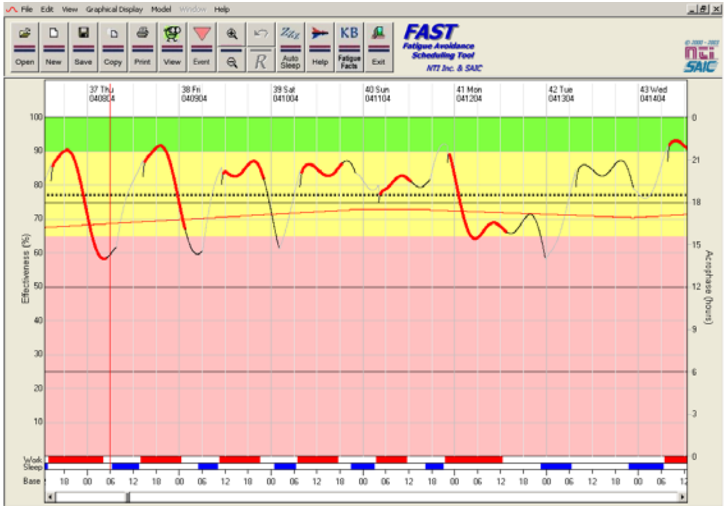


Exhibit 5-7: Driver on a 'Variable' Schedule



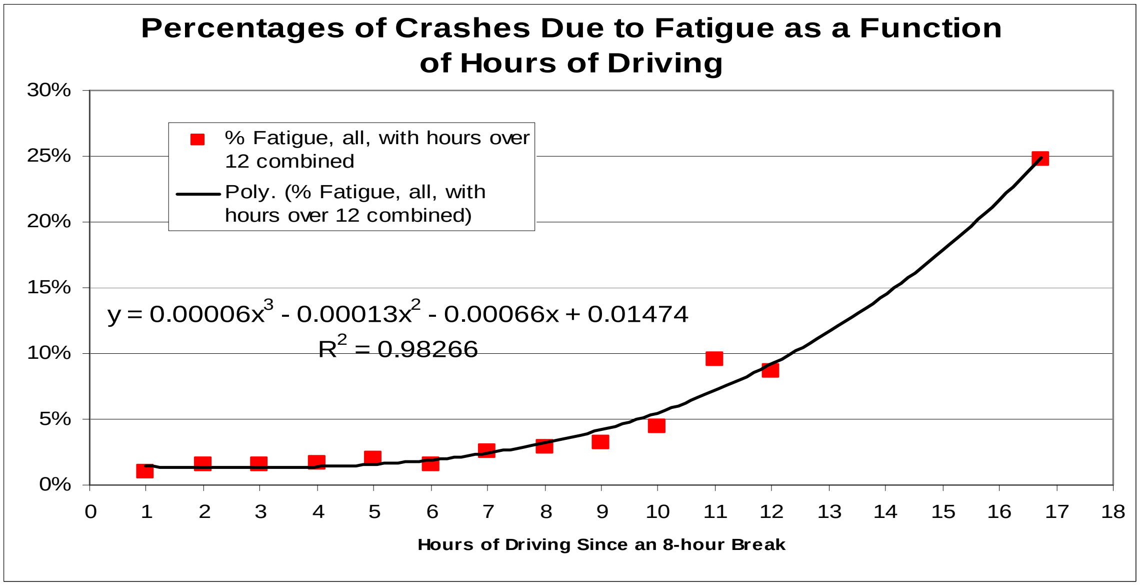
The ‘regular’ driver, in addition to showing a higher overall effectiveness, also shows much less variability in effectiveness. The large drops in effectiveness shown in the output of the variable-schedule driver are a characteristic of a constantly changing schedule. In the two examples above, the average driver effectiveness over a one-year period for the ‘regular’ schedule driver was 92.95%. This compares very favorably to an average effectiveness of 77.89% for the driver with the variable schedule.

5.4.3. TOT Analysis

The TOT analysis relies on crash risks by hours driving, derived from Ken Campbell’s analysis of Trucks in Fatal Accidents (TIFA) data as described in Section 5.2.1. Exhibit 5-11 takes the fatigue-related crash risk by driving hour from Ken Campbell’s research and fits a cubic curve to the data. Note that that the fitted curve suggests that the particularly high risk factor observed by Campbell for the 11^{th} hour may be an outlier. Relative risk data for the 13^{th} driving hour and beyond were combined due to the very small number of crashes that occurred in each of these hours (i.e., in some hours, there were no fatigue-related crashes recorded). Note: This data aggregation for points in the 13^{th} driving hour and beyond is further explained in Appendix (V) and alternative analytical approaches are implemented.

Campbell’s data express relative risk as a multiplier of the first hour risk. This has been converted into actual percentage crash risk. As noted earlier in Section 5.2.1 of this chapter, the TIFA data compiled by Campbell have several limitations, including: (1) the number of fatigue-related crashes in the 11^{th} hour and beyond is very small; (2) because driving beyond 10 hours was illegal under the pre-2003 rule for many drivers (but excluding those exempt from the HOS provisions), the relative risk of the subpopulation of commercial drivers admitting to illegal driving during the 11^{th} hour may not reflect the relative risk of drivers operating legally under the new rule; and (3) because the required off-duty period pre-2003 was only 8 hours long, and not the longer 10-hour period off duty currently required, the 1991-2002 TIFA data analyzed here reflects drivers who may well have been more fatigued at any given time on task than drivers would have been if the data had been collected under the 2003 rule. Limitations (2) and (3), all other things equal, argue that the Campbell data may over-estimate the true risk of driving during the 11^{th} hour in the current state of the world. Limitation (1) argues that any result from the Campbell data carries with it a considerable amount of uncertainty. Because of this uncertainty, Section 6 presents a sensitivity analysis to test the robustness of the conclusions of the impact analysis.

Exhibit 5-11
Fatigue Crash Risk as a Function of Hours of Driving



The curve in Exhibit 5-11 shows that fatigue-related crash risk starts rising after the six or seven hours. Therefore, for the eighth hour and beyond crash risk was increased by a factor equal to the ratio between the estimate for each hour represented by the polynomial and the average fatigue crash risk. These factors were applied in the procedure for estimating crash risk from the performance data provided by the SAFTE/FAST tool, as described in Section 5.4.4, below.

Challenges to the TOT Analysis

The TOT analysis presented above, and used for the 2005 HOS RIA, was challenged in several ways. First, petitioners questioned the use of a function that combined the data points beyond 12 hours and treated them as though they fell near hour 17 rather than at some other point on the graph (e.g., at 13 hours).

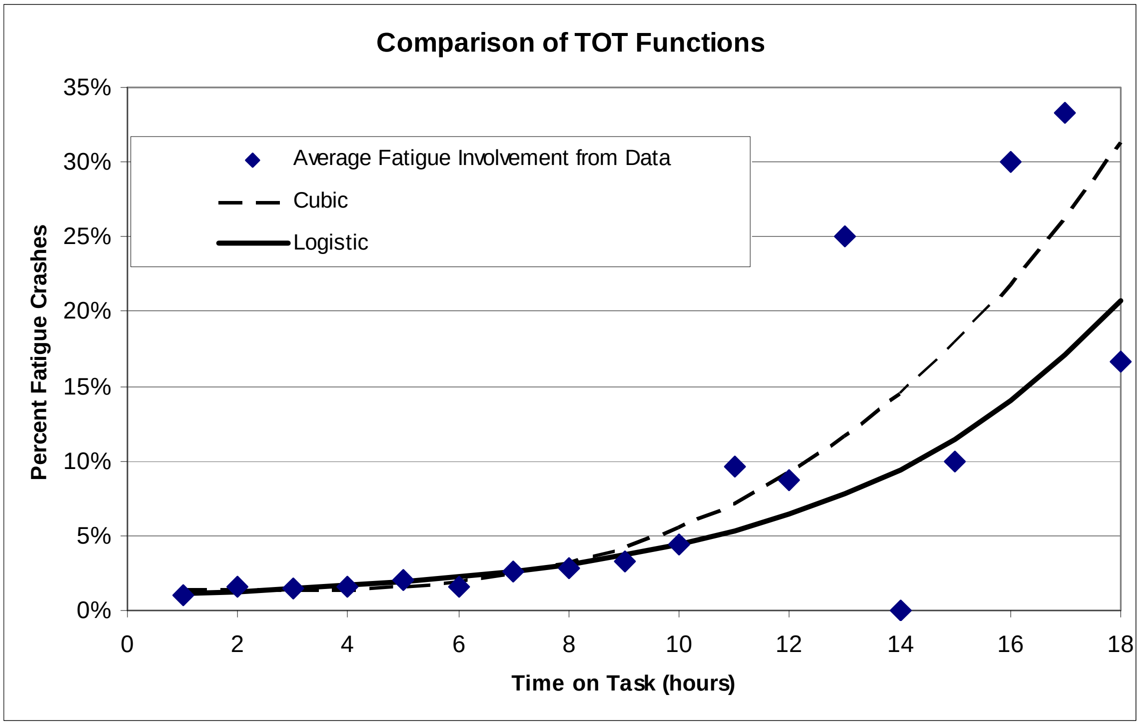
Second, the reason for dividing the predicted fatigue levels from the TOT function by the average fatigue-related crash rate was questioned, with the implication that this approach reduced the apparent impact of fatigue.

Third, the value used to divide through the predicted fatigue levels was criticized as being based on TOT hours 1-11, rather than the hours 1-10 that would be allowed in the alternative that eliminated the 11th hour.

The use of a combined data point at the average TOT and average fatigue crash risk, and the use of a polynomial function, was a reasonable approach to the need to fit a function and use the limited data available for high TOT values. It can, however, be improved. One flaw in the approach is that the polynomial functional form allows for fatigue percentages that are greater than 100% or less than zero, which are outside the range of possible values for fatigue percentages. Another problem is that, by combining the data beyond the 12th hour, the analysis leaves out some of the available information: for example, it does not consider the relative numbers of crashes at different TOT levels.

In response, we have re-estimated the function using a more appropriate approach. The re-estimation used a flexible logistic function, which by nature allows predicted fatigue values to vary only between 0 and 100 percent. In implementing this approach, every available data point was used, and several degrees of polynomials were tested to find the best-fitting logistic curve. This approach yielded a TOT fatigue crash risk function that was generally similar to the original polynomial (specifically, a cubic) function for low TOT levels, but lay somewhat lower at the 11th hour.   The original and new functional curves plotted to the TIFA data are shown in Exhibit 5-12. Also, details of the updated estimation approach are presented in Appendix (V).

Exhibit 5-12
Fatigue Crash Risk as a Function of Hours of Driving



5.4.4. Crash Risk Analysis

This section explains how the SAFTE/FAST tool outputs and the relationship between crash risk and TOT are combined to provide an estimate of crash risk for each HOS option. The steps in the analysis are as follows:

- Estimate raw crash risk increment from SAFTE/FAST performance data for each schedule

- Apply the TOT adjustments to all schedules that exceed 7 hours driving time in one shift.

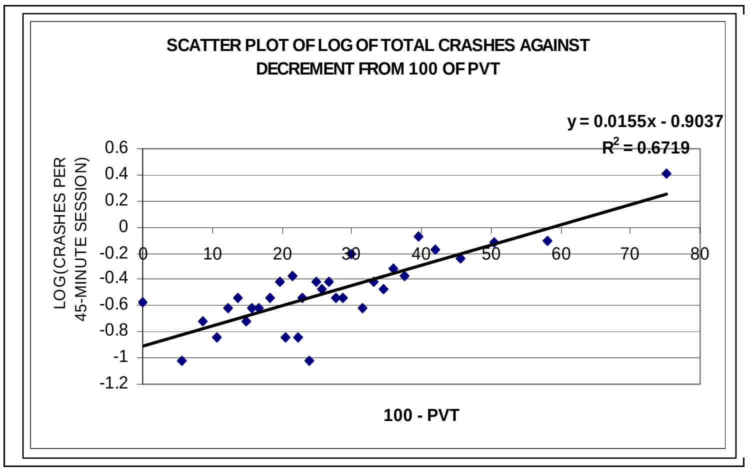
- Weight and average crash risk increment values for individual schedules (after applying the TOT adjustment), to obtain crash risk increments for each trucking industry segment and for the industry overall.

- Adjust and scale the raw crash risk increments so that industry-wide crash risk attributable to fatigue matches the projected real-world fatigue-related crash risk in the baseline (Option 1).

This procedure is identical to that used in the 2003 HOS RIA, except for the addition of the TOT adjustment to crash risk estimates. The following paragraphs summarize the analysis steps. Further details can be found in Appendix G of the 2003 RIA.

Estimate raw crash increment. The primary source of data to form a link between crash risk and PVT scores produced by the SAFTE/FAST tool was a laboratory study carried out by Walter Reed Army Institute of Research, in which driving performance on a truck simulator was compared with PVT measurements for different levels of sleep deprivation (see Section 5.2.3). A robust straight line relationship between the log of crashes during a 45 minute driving session and fatigue level as measured by 100-PVT score was obtained. Exhibit 5-13 shows the scatter plot and the linear relationship. PVT scores were scaled so that a score of 100 indicates a fully rested individual.

Exhibit 5-13
Relationship of PVT to Relative Crash Risks



TOT Adjustment. Based on the discussion in Sections 5.2.1 and 5.4.3, a driving time risk factor was applied to all schedules over 7 hours. The table, Exhibit 5-14, lists the increase factor for average crash risk for drive times of 8 or more hours, calculated from the polynomial shown in Exhibit 5-11.

Exhibit 5-14 TOT Crash Risk Multipliers	
Driving Time in One Tour of Duty	**Risk Increase Relative to Average Driving Hours**
8	1.09
8.5	1.26
9	1.44
9.5	1.65
10	1.89
10.5	2.16
11	2.46

Source: Exhibit 5-11 and FMCSA calculations

These factors were applied to each crash risk increment calculated by the SAFTE/FAST model.

The adjustment factors shown in Exhibit 5-14 were created by dividing the predicted fatigue crash risk from the cubic function by 2.92%, which was the average fatigue level for the first 11 hour seen in the underlying data. This choice was questioned, and it was suggested that the average value of the function for the first 10 hours would have been more appropriate. Because of the details of the analysis, however, and the way the results were scaled, the choice of divisor has, in theory, no effect on the results. In a properly implemented analysis, the results will be the same whether the adjustment factor is the TOT function divided by 2.92%, or by 2.5%, or even by 100%: the predicted change in crashes caused by banning the 11th hour will be the same. In the mathematics of applying the fatigue adjustment factors to both the baseline and policy cases, the divisor used to create the adjustment factor affects the numerators and denominators of a ratio in the same way. Thus, the divisor cancels itself out, and has no effect on the estimate of the relative fatigue crash percentages with and without the 11th hour. This conclusion is demonstrated in Appendix (V).

Corrections to the TOT Analysis

Two issues that remain to be addressed in revising the estimated benefits of banning the 11^{th} hour: the function was imperfect, and the approach laid out above was implemented incorrectly – all TOT hours should have been adjusted, but only those 8 or greater were given adjustment factors. It was possible to calculate how these two issues would have affected the estimated benefits of banning the 11^{th} hour by estimating the change in the average fatigue crash risk twice: once with the original approach, and once with a corrected approach.

For each approach, this was accomplished by

- estimating the fraction of driving that was done in each TOT hour assuming that driving 11 hours was legal;
- multiplying the fraction for each TOT hour by a TOT fatigue adjustment factor, and
- finding the sum of these products;
- repeating these calculations for a case that allowed only 10 hours of driving; and
- finding the percentage change in the fatigue percentages between the 11 and 10 hour cases.

The results of carrying out these steps are presented in section 6.4.

Calculate Raw Crash Risk Increments by Industry Segment. The crash risk increments as calculated by the SAFTE/FAST model, with TOT adjustment for shifts of 8 hours and over, were averaged for each truck industry segment and for the industry overall.

Estimate Actual Fatigue-Related Crash Risk. The final stem in the analysis is to convert the raw crash risk increments to an estimate of the actual variation of crash risk for different HOS alternatives and industry segments. This is achieved by calibrating the crash risk increments for a base case to real-world fatigue related crash data. The procedure is identical to that described in Chapter 8 of the 2003 RIA report. The raw crash risk increments are the percentage increase in crash risk over the crash risk for a fully rested driver. Thus the proportional change in fatigue-related crashes between two HOS scenarios is represented by the ratio:

[100+crash increment for HOS option A]/[100+crash increment for HOS option B]

The base case for this analysis is the fatigue-related crash risk for LH truck operations under the 2003 HOS regulations, estimated at 7% of all truck involved crashes. The fatigue-related crash risk percentage for each of the HOS scenarios analyzed in this analysis is then as shown below:

$$\frac{7.0 \text{ x [100+crash increment for revised HOS option]}}{\text{[100+crash risk increment for 2003 HOS option]}}$$

The calculation is repeated for each HOS option analyzed.

6. MODELING RESULTS

This chapter presents the results of the modeling of carrier operations under the options. The measured impacts of the HOS options on productivity are presented first, followed by a description of the weighting procedure used to combine the individual simulation runs into weighted average estimates of productivity impacts. These productivity changes are then translated into total cost estimates and changes in the number of drivers required. The next section presents and discusses in a parallel fashion the estimated crash risk impacts of the options for each run, the weighted impacts on crashes, and the value of those impacts.

6.1 MEASURED PRODUCTIVITY IMPACTS OF OPTIONS ON LH OPERATIONS

Exhibit 6-1 shows the average percentage change in driving hours between the options. Only non-split-sleeper-berth operations are included in the table because of the strict limits on splitting common to both options. Most of the substantial loss of productivity seen to result from Option 2 comes from the loss of the restart period. For the random drivers, the lack of a regularly scheduled off-duty period means that a short restart can be very advantageous, especially for the hard-working drivers that were modeled. The exceptions to this trend can be explained by the reduced value of the restart in particular cases. The regular weekly and daily routes (which generally have a full weekend off), and team drivers (who share duty hours each day) do not need to restart because their cumulative 8-day on-duty totals do not reach 70 hours. Finally, it should be noted that the one case of a negative measured impact of Option 2 is an artifact of the random elements in the simulation procedure, and would not be expected to persist if these runs were repeated a large number of times.

Exhibit 6-1
Estimated Changes in Long-Haul Productivity by Option and Case

			Option 2 Compared to Option 1
Run characteristics			**Relative Reduction in driving hours**
For-hire Random		SR	24.1%
		LR	21.4%
		LH	20.4%
Regular Routes (Private TL, LTL, regular for-hire)	Full weekend off	Weekly route	16.1%
		Daily route**	-2.0%
	Six-day work week	Weekly route	29.2%
		Daily route	8.9%
Team drivers*			5.00%

* This impact estimate was based on simplified scenarios described below rather than model runs.

For Option 2, the team drivers were expected to lose 5 percent of their productivity as a result of the loss of the 11th hour of driving. This impact could occur despite the fact that teams are not expected to use more than 10 hours per day per driver on average. We found a consensus among industry observers[41] that teams, on average, do not exceed 20 hours a day of driving. The average team driver, therefore, does not exceed an average of ten hours of driving in 24 hours on the clock. It does not, however, follow from this that there is no productivity loss for team operation from eliminating the 11th hour of driving.

The cost stems from the fact that a driver is very unlikely to find a suitable place to stop at the precise moment that his tenth driving hour ends. As long as he can use part of the 11th hour, this is not a problem. A driver can take what he deems as a convenient opportunity to stop, whether before or after the end of the tenth hour. The driver's convenience and the spacing of stopping places would mean some driving tours over ten hours and some under. Team members' driving times, then, would approximate an average of ten hours.

The result is different, however, when the drivers are limited to ten hours each. Since they cannot drive after ten hours, they must stop, effectively, before ten hours. Thus, the average driving time for each team member is necessarily less than ten hours; a few driving tours might end very close to ten hours, but many would have to be well short of that, possibly anywhere in the range of nine to ten hours.

It is not feasible to offer a precise estimate of when in the nine-to-ten-hour range the average driver would stop. This would depend on the spacing of suitable stopping places on the route along which the team is moving. It also depends on what the team members would regard as suitable. Some gas stations have enough paved area for an 18-wheel tractor-trailer to park quickly. When one of the drivers is approaching the ten-hour limit, however, it is very likely that the vehicle has been moving for four or five hours and both team members would prefer more extensive facilities than a gas station would offer. Truck stops will be considerably less closely spaced along a highway than gas stations. To be conservative, we have assumed that the team will pass only one truck stop in the tenth hour and that could happen at any point in that hour. On this basis, the average driving time for each team member would be 9.5 hours rather than 10, a reduction of 5 percent.

6.2 WEIGHTING OF THE INDIVIDUAL RUNS

Because the impacts of the options in the individual runs varies so widely, it was important to find the weighted average impacts across the runs, rather than relying on unweighted averages or simply presenting the range. The weighting procedure was based, in the first instance, on estimates of the fraction of total VMT accounted for by each operational pattern. Teams, for example, account for about 9 percent of total LH VMT, and LTL over-the-road operations account for another 5 percent. The remaining VMT is split roughly equally between for-hire and private fleets – 42 and 44 percent respectively. As noted in Chapter 2, we have found that about 60 percent of for-hire VMT can be considered random as opposed to regular. Furthermore, long regional and long haul operations are of greater magnitude than shorter operations, with about 38, 42, and 20 percent of VMT for these operational categories, respectively. We have also found that more than half of for-hire operations, and somewhat less than half of private fleet operations, are intensive enough to press the HOS limits, and should therefore be affected by changes in those limits.

[41] See section 2.1.6

In addition to representing the typical patterns in the industry, however, it was important that the modeling reproduced the usage of the important features of the HOS rules that differ between the options. To ensure that the weighting resulting in an accurate reflection of the use of these features (and therefore that the impacts of the options is realistically measured), the weights were altered to some degree, relying on data such as that shown in Exhibit 6-2, below. To match our estimate of the aggregate degree to which the 11th hour was used across the industry, we increased the assumed percentage of operations that were intensive enough to be affected by changes in the HOS rules beyond the degree indicated by the data. In the case of random TL operations, only a slight decrease (from 65% to 58%) was needed. In the case of regular operations, it was necessary to increase the assumed degree of intensive operations to 45%, compared to the 31% that emerged strictly from our analysis of the data in the FMCSA survey.[42] Because the options being compared did not allow split sleeper berths, we compared only runs that did not allow them.

6.3 WEIGHTED LH PRODUCTIVITY IMPACTS

The weights used in the modeling are shown in Exhibit 6-3. This table also shows each operational type's contribution to the nationwide weighted impact, which is calculated by multiplying the relative impacts in Exhibit 6-1 by the weights.

The sums of these weighted contributions are also shown at the bottom of the table. Option 2 was found to reduce average driver productivity by about 7.30 percent. Multiplying this weighted average productivity impacts by the costs per percent decrease in productivity presented in Chapter 4 – $335 million – yields about $2,443 million on an annual basis.

Exhibit 6-2
Use of the 11th Hour by Run

			Percentage of Tours with More than 10 hours of Driving in Option 1
Run Characteristics			
For-hire, random	Using split sleeper berths	Short Regional	0%
		Long Regional	10%
		Long Haul	21%
	No split sleeper berths	Short Regional	0%
		Long Regional	11%
		Long Haul	28%

[42] See Exhibit A-4. This increase in the percentage of the regular drivers that work intensively could result in an overstatement of the impacts of the options, particularly Options 3 and 4, if private fleets actually have relatively little intense operation. On the other hand, data used for the previous RIA (see Exhibit C-1, p. C-3 of the appendices) found a relatively small difference in intensity of effort between for-hire and private fleet operations – 44% to 46% and 32% to 37%, respectively – which we expect to track differences between random and regular operations. Thus, it may be that the FMCSA survey data understates the intensity of regular operations to some degree.

Exhibit 6-2 Use of the 11th Hour by Run			
			Percentage of Tours with More than 10 hours of Driving in Option 1
Run Characteristics			
Regular routes (Private TL, LTL, regular for-hire)	Full weekend off	Weekly route	31%
		Daily route	55%
	Six-day work week	Weekly route	29%
		Daily route	34%
Team drivers*	Using split sleeper berths		50%
	No split sleeper berths		50%

*Estimates for team drivers are based on simplified assumptions rather than modeling.

Exhibit 6-3 Weighted Changes in LH Productivity by Option and Case				
			Weight	**Option 2 Cost**
Run characteristics				
For-hire, random		SR	2.9%	0.70%
		LR	6.1%	1.32%
		LH	5.6%	1.13%
Regular routes (Private TL, LTL, regular for-hire)	Full weekend off	Weekly	7.3%	1.18%
		Daily	8.5%	-0.18%
	Six-day work week	Weekly	6.4%	1.86%
		Daily	9.5%	0.83%
Team drivers			9.0%	0.45%
Unaffected (due to less-intense schedules)			44.6%	0.00%
Total			100.0%	7.30%

Note: totals do not add exactly due to rounding.

Exhibit 6-4 Incremental Annual Costs of the Options for LH Operations Relative to Option 1	
	Option 2
Change in LH Productivity	-7.30%
Cost per 1% Decrease in LH Productivity (millions of 2005$)	$335
Total Annual Incremental Cost	$2,443

Source: FMCSA analysis.

Increases in Drivers

If the same total ton-miles of freight would be transported by truck under all four options, the reductions in LH productivity could be translated directly into percentage increases in the number of drivers needed by the industry. Thus, Option 2 would require an additional 7.3% *1.63 million existing long-haul drivers or about 120 thousand long-haul drivers. To the extent that these added drivers are less experienced than the typical driver, this influx could result in higher crash rates: experience is associated with greater safety, as shown in Section 8.7 of the 2003 HOS RIA.[43]

As discussed in Chapter 4, reduced productivity could be expected to raise the trucking rates slightly, leading to slightly more competition from rail. We estimate that the resulting mode shift would cut the need for additional drivers slightly, and the shift away from trucking would by itself tend to reduce crashes slightly.

6.4 Crash Risk Results by Operational Case

The results of the crash risk modeling are presented in Exhibit 6-5, with and without scaling the results to yield an average fatigue-related value of 7 percent in Option 1; the exhibit also shows the adjustment based on the revised TOT modeling.

Weighting the crash risk results in the same manner as the productivity results, we found the overall changes in crash risks to be small. Option 2 was originally estimated to provide a risk reduction of about 0.5 percent relative to Option 1, of which 0.3 percent was estimated to be due to the TOT effect. That analysis inadequately accounted for the TOT effect, which necessitated a correction. The correction was determined by estimating the degree to which measured benefits would rise if data from the same two options, one with and one without the 11th hour, were reanalyzed using an improved TOT function. Using the original TOT function, the fatigue crash risk appeared to fall by 3.6% as a result of the TOT effects. Under the revised analysis, the fatigue crash risk appeared to fall by 5.1%. Thus, in the absence of any differences in fatigue for non-TOT effects, correcting the TOT approach is expected to increase the projected TOT benefits by a factor of about 5.1%/3.6%, or about 1.42 times. If all of the 0.3 percent reduction

43 2003 HOS RIA, p. 8-34.

in damages originally estimated for eliminating the 11th hour had been due to the reduction in average TOT, the true benefits would be about 1.42 * 0.3 percent, or close to 0.43 percent.[44] The added benefits of a 0.13 percent reduction in LH crash damages have been added to the benefits of Option 2 to correct for the underestimation of the TOT benefits in the original analysis. Thus, after correcting for problems with the original TOT analysis, Option 2 is now estimated to provide about a (0.5 percent + 0.13 percent) or 0.63 percent reduction in LH crash damages.

6.5 VALUE OF THE LH CRASH RISK CHANGES

These percentage changes in risk were valued by multiplying them by an estimate of the total annual damage associated with heavy-duty LH truck crashes. A recently updated study of those damages showed that the average damages per crash was $91,112 in 2005$, and an average of 433,872 crashes per year, for a total of $39.53 billion in truck crashes.[45] That study was based on a $3 million value per statistical life, though it shows how the results would change for other values. The Department of Transportation has recently begun using a VSL of $5.8 million in 2007$, which is about $5.48 million in 2005$. Applying this new VSL yields a higher damage per crash of $135,622 in 2005$, which implies that total damages are almost $59 billion in 2005$.[46] The 2003 RIA also presented an estimate of the percentage of total damages that were caused by the LH segment. Applying the same percentage – just over 58 percent – to $59 billion yields just over $34 billion. The reduction in risk attributable to Option 2, given this total value, is 0.63% * $34 billion or about $214 million per year. These risk reduction changes are much smaller than the cost changes attributable to the options.

Exhibit 6-5
Incremental Crash Risk Estimates

			Option 2 Compared to Option 1
Run characteristics			**Relative Change in Crash Risk**
For-hire, random		SR	1.1%
		LR	-6.9%
		LH	-9.3%
Regular routes (Private TL, LTL, regular for-hire)	Full weekend off	Weekly	0.2%
		Daily	-0.7%
	Six-day work week	Weekly	-0.7%
		Daily	-0.9%
Team drivers*			-0.7%
Weighted Average Impacts (raw)			-1.2%
Weighted Average Impacts (scaled)			-0.5%
Weighted Average Impacts (scaled and			-0.63%

44 This change was originally estimated to be -0.125; a slight correction to the weighting of industry segments and rounding led to an increase to -0.13.

45 Zaloshnja, E. and Miller, T. (2006). Unit Costs of Medium and Heavy Truck Crashes, Final Report for Federal Motor Carrier Safety Administration, Federal Highway Administration.

46 In addition to the adjustment based on the new VSL, the revised estimate of crash costs also corrects for double-counting of "lost productivity from delays" in the published version.

adjusted to account for revised TOT analysis)	

*Based on FMCSA analysis of simplified scenarios.

6.6 NET COSTS BY OPTION

Exhibit 6-6 summarizes the annualized costs, benefits, and net costs of Option 2 relative to Option 1.

Exhibit 6-6
Net Incremental Annual Costs of Option 2 Relative to Option 1
(millions of 2005$)

Total Annual Incremental Cost	$2,443
Total Crash Reduction Benefits	$214
Net Annual Costs	$2,229

6.7 LIMITATIONS AND SENSITIVITIES

The estimates of costs and benefits of the options relative to one another are based on data, assumptions, and modeling, each of which are subject to uncertainties of various kinds. We have estimated the effects on the cost and benefit calculations if variants of some of the assumptions used in the analysis were used.

6.7.1 Elimination of the 11th Hour of Driving in Option 2

In addition to Options 1 and 2, we also examined a more restrictive variant of Option 1. That option limited driving to 10 hours in a tour of duty. This more restrictive option was found to provide more benefits than Option 1, but at substantially higher cost. Crash risks were originally found to be reduced by about 0.3 percent relative to Option 1. As discussed in Sections 5.4.3, 5.4.4, 6.4 and Appendix (V), this variant is now estimated to reduce LH crashes by 0.43 percent.[47] This reduction is estimated, using the recent updates to the number of crashes, the damages caused by each crash, and the VSL described above, to be worth $146 million per year.

The projected costs, however, are much higher. They were originally estimated to be $586 million more per year than under Option 1, which has been updated for inflation, industry growth, and industry coverage to $686 million.[48] This estimate was made by finding the average reduction in driver productivity in shifting between a case that assumed the characteristics of Option 1 and a variant that capped driving hours at 10. The average change in productivity,

47 This reduction in crashes was originally estimated to be 0.425 percent, but that estimate was found to have excluded effects on LTL operations. Including those operations, the reduction in crashes is now estimated to be a slightly higher 0.43 percent.

48 Compared to the $146 million increase in benefits, the increase in costs is more than four times greater.

weighting by the fraction of all driving estimated to fall into each operational case, was just over 2.0 percent.[49]

The valuation of the loss of 2.05 percent in productivity was accomplished using the same method as for the other cost analyses, which found that each percentage point reduction in productivity translated to a loss of $335 million per year. Multiplying the 2.05 percentage point reduction in productivity per driver by the $335 million cost per percentage point yielded an estimated cost of $686 million per year for eliminating the 11th hour. Subtracting the benefits of $146 million leaves estimated net costs of $540 million.

Because various factors and assumptions that feed into the analyses of benefits are uncertain, the costs and benefits of the incremental elimination of the 11th hour could be higher or lower than $686 million and $146 annually. To test whether reasonable changes in the most important assumptions could swing the overall cost-benefit analysis to favor 10 hours in Option 1, we have conducted sensitivity analyses that change each of several key assumptions in turn, and another in which they are changed as a group. The first two single-assumption sensitivity analyses make changes that favor eliminating the 11th hour of driving. These two sensitivity analyses test whether or not Option 1 is still cost-beneficial relative to the variant allowing no more than 10 hours of driving. In other words, we "stress test" the cost-benefit analysis of Option 1 by testing whether unfavorable assumptions would reverse the selection of Option 1 in favor of its more-restrictive variant.

Value Per Statistical Life Saved

Crash reduction benefits were estimated based on examinations of the outcomes of crashes (property damage only, injuries and property damage, or fatalities) and detailed assessments of the social costs of those outcomes. Repair costs, costs of medical treatment, lost time due to delays, and productivity losses due to injuries and deaths are all included. In addition, deaths are valued by computing how many “quality adjusted life years” the victims lose. As described in Section 6.5, a VSL of $5.48 million was used as the basis for the calculation of these damages. In 2004, the Office of Management and Budget (OMB) issued guidance to Federal agencies with regard to conducting regulatory impact analyses, including information on the monetary value of a statistical life (VSL). In this guidance, OMB indicated that, “A substantial majority of the resulting estimates of VSL vary from roughly $1 million to $10 million per statistical life.” [OMB Circular A-4, p.30]. Using a higher VSL would result in greater damages from crashes.

If a higher value were assumed for avoiding each fatality, the total benefits for reducing crashes through the elimination of the 11th hour of driving would rise, and the net benefits of Option 1 with 10 hours would increase. The effect of raising the VSL from $5.48 million to $10 million (assumed to be in 2004$, which is the equivalent of $10.32 million in 2005$), the upper limit of the range recommended by OMB, can be calculated using a table presented in the study on which FMCSA’s estimates of the value crash damages was based.[50] If VSL is taken to be $10.32 million instead of $5.48 million, the total damages from all truck related crashes, then, rise to

49 This reduction in productivity was originally estimated to be 1.97 percent, but that estimate was found to have excluded effects on LTL operations. Including those operations, the reduction in productivity is now estimated to be a slightly higher 2.05 percent.

50 Zaloshnja and Miller 2006, tables 4 and 5.

$101.9 billion, and the total damages from LH crashes rise to $59 billion. Using this value of damages in place of the original $34 billion amounts to an increase by a factor of 59/34, or 1.74.

The larger VSL would thus increase total benefits for Option 1 with 10 hours from $146 million annually to $254 million.[51] Since the annual costs of Option 1 with 10 hours are unchanged at $686 million, the net cost becomes $432 million ($686 - $254). Although almost doubling the VSL does lower the net cost, eliminating the 11th hour of driving in Option 1 is still not cost-beneficial.

Increased Relative Risk from the 11th Hour

As explained in Chapter 5, the benefits of eliminating the 11th hour were calculated using an added TOT multiplier for crash risks for long hours of driving. The magnitude of this multiplier was calculated on the basis of TIFA data for over 30,000 fatal crashes. The analysis measured the percentage of fatal crashes considered to be fatigue-related as a function of number of hours behind the wheel since an extended break. The fatigue-related percentage was low for the first six or seven hours, and then generally increased with each additional driving hour.

Because the regression equation was based on a sample of data and is only an estimate with error, the true relative risks of fatigue involvement in the 11th hour could be higher or lower. To estimate how much higher this relative risk is likely to be, a "bootstrap" analysis of the data set was conducted.[52] In this analysis, the logistic regression equation was re-estimated 1,000 times, using data sets randomly selected from over 30,000 original data points.[53] Across these 1,000 equations, the upper bound of the 95 percent confidence interval (the 50th highest out of 1,000) of the increased risk at the 11th hour compared to the average of the first 10 was 3.65 percent, which is about 23 percent higher than the point estimate, and the upper bound of the 99 percent confidence interval (the 5th highest out of 1,000) was 3.91, which is about 32 percent higher than the point estimate. Thus, there is less than a 1% chance that the additional risk caused by driving in the 11th hour is more than about 1.32 times greater than the estimate used in the cost-benefit analysis of Option 2 that appears in Exhibit 6-6.[54]

If the risk caused by allowing operators to drive for 11 hours is, in fact, 1.32 greater than had been assumed in the cost-benefit analysis of Option 2, then the benefits for Option 1 with only 10 driving hours would rise from $146 million to $192 million annually. Consequently, under the higher risk of driving the 11th hour, the net cost of Option 1 with 10 hours becomes $494 million per year (or $686 - $192). Thus, while increasing the relative risk of a fatigue-related crash while

51 $254 million = $146 million x 1.74

52 The bootstrap regression procedure is described in Appendix (V).

53 A bootstrap analysis samples the original dataset with replacement, which means that it creates a new dataset with the same number of observations as the original dataset. After each data point is randomly selected as part of an individual data set, it could be chosen again in the same dataset. The variation introduced by this method allows for the calculation of confidence intervals for the regression parameter estimates, and therefore a confidence interval for the relative risk of the 11th hour of driving.

54 We acknowledge that this type of analysis explicitly identifies one major contributor to the uncertainty of the estimate (sampling error) but does not explicitly correct for more general sources of uncertainty, such as whether or not this relative risk estimate is an unbiased estimate of the true risk of the 11th hour of driving for the reasons discussed earlier in the analysis. Implicitly, however, the increase in relative risk identified by this sensitivity analysis could also be due to a downward-biased original estimate, or indeed any other source of uncertainty.

driving the 11th hour does reduce the net costs, eliminating the 11th hour is still not cost-beneficial. In fact, in order for eliminating the 11th hour to break even in cost-benefit terms, the TOT effect would have to be 4.69 times the point estimate, rather than only 1.32 times. Only by multiplying the point estimate of the increased risk of crashes in the 11th hour would the benefits rise to $686 million per year.

Overall Use of the 11th Driving Hour

The two sensitivity analyses above stress-tested Option 1 by making plausible changes in assumptions that favored eliminating the 11th driving hour. We next made a sensitivity analysis of changing another key parameter--the use of the 11th driving hour. Reducing the use of the 11th hour would move the cost-benefit analysis toward Option 1 with 10 hours, but we could not plausibly make that assumption: as the 11th hour of driving becomes more incorporated into normal operations in the future, we believe its use much more likely to increase rather than decrease. Increasing that percentage would increase the costs to the same degree as the crash reduction benefits. For example, a doubling of the percentage would lead to estimated costs for Option 1 with 10 hours of about +$1,372 million (i.e., $686 million *2). Benefits for Option 1 with 10 hours would become $292 million annually (i.e., $146 million *2). Net costs for Option 1 with 10 hours would rise from $540 million annually to $1,080 million annually. If the use of the 11th driving hour doubled, Option 1 with 10 hours would become even less cost-beneficial relative to the original Option 1. Also note that even if the use of the 11th hour dropped, because the use of the 11th hour is cost-beneficial regardless of how often it is used, variation of this single assumption could never make the restriction of the 11th hour of driving cost-beneficial. In other words, this assumption is not decision critical with regard to whether or not to restrict the 11th hour of driving.

Baseline Risks of Fatigue-related Crashes

One important reason that the cost-effectiveness of banning the 11th hour is unfavorable, despite the fact that fatigue-related crashes rise to several times their average value as TOT increases, is that fatigue is associated with only a fraction of all crashes. Thus, even if fatigue-related crashes are two to three times as likely in the 11th hour as in the average hour, the overall change of a crash increases only moderately. For the 2003 RIA, fatigue was estimated to cause 8.15 percent of crashes. If in a given hour that risk increases by a factor of 2.5, to about 20.4 percent overall, then overall crash risks in that hour would rise by only about 12 percent (i.e., to 20.4% – 8.15%). In addition, because the 2003 rule was projected to reduce fatigue-related crashes considerably, the incremental effect of the 11th hour would be even smaller.

There is, however, uncertainty about the baseline degree of fatigue. In the 2003 RIA, sensitivity analyses were prepared using alternative assumptions of 5 and 15 percent, in addition to 8.15 percent, because most comments relating to the prevalence of fatigue as a cause of accidents posited values within that range. If the 15 percent value were used for the baseline (in the pre-2003 situation), the estimated crashes caused by fatigue would rise by a factor of 15/8.15 or 1.84 (i.e., an increase of 84 percent of the base). This increase would carry through to the impact of eliminating the 11th hour, meaning that assuming a higher baseline fatigue percentage would raise the benefits from $146 million to $146 * 1.84, or $269 million. This change would imply net costs of $686 million - $269 million or about $417 million. Though increasing the baseline risk of fatigue-related crashes from 8.15 percent to 15 percent does reduce the annual net cost (from \$540 million to \$417 million), eliminating the 11th hour of driving in Option 1 is still not cost-beneficial.

Combinations of Changes in Assumptions

None of the sensitivity analyses described above show a balance of costs and benefits that supports Option 1 with driving restricted to 10 hours. These sensitivity analyses were all conducted, however, with only one assumption changing at a time, and it is at least possible that the most realistic answer would be obtained if the three assumptions that moved the cost-benefit results toward eliminating the 11th hour were changed simultaneously. Take the combined sensitivity analysis for: (1) the value of a statistical life assumed to be at the high end of its range (\$10.3 million, instead of \$5.5 million); (2) the risk of the 11th hour assumed to be at the upper bound of the 99 percent confidence interval (about 1.3 times the value used in the basic analysis); and (3) the baseline fatigue percentage assumed to be at the high end of its range (15 percent instead of 8.15 percent). In that case, the total benefits of Option 1 with 10 hours of driving would be about \$615 million per year, while total costs would still be \$686 million annually, leaving a net cost of about \$71 million per year. Thus, it appears highly unlikely that banning the 11th hour would lead to a cost-beneficial rule, even with all favorable assumptions.

These points are summarized in Exhibit 6-7, which presents the effects of different safety-related assumptions on the net costs, benefits, and net benefits of the 10-hour variant of Option 1, relative to Option 1.

Exhibit 6-7
Sensitivity Analyses of Net Benefits, 10-hour Driving Limit
(millions of 2004\$)

	Net Costs Relative to Option 1	Safety Benefits Relative to Option 1	Net Benefit Relative to Option 1
Basic Assumptions	686	146	- 540
Twice as Much Use of 11th Hour	1,372	292	- 1,080
Higher Value of Statistical Life (VSL)	686	254	- 432
Higher TOT Impact	686	192	- 494
Higher Baseline Fatigue	686	269	- 417
Higher VSL, TOT Impact, and Baseline Fatigue	686	615	- 71

The column at the right shows the net advantage of Option 1 over the alternate version with the 10-hour limit. The first column of figures is the net cost of the 10-hour variant relative to Option 1 under different assumptions; because only the change in the assumption about the use of the 11th hour has an effect on costs, very little changes in this column from one assumption to the next. The next column of figures shows the safety benefits of the 10-hour variant relative to Option 1; the version of Option 1 with the 10-hour limit shows an increase in benefits in response to changing the safety assumptions, and shows the highest increase in the last row, which combines the preceding three changes in assumptions. The third column of figures is the difference between the previous two – in other words, the net benefits of the variant. For each set of assumptions, the 10-hour variant has negative net benefits relative to Option 1. Thus, even under the most favorable assumptions, eliminating the 11th hours does not appear to be cost-effective.

6.7.2 Use of the 11th Hour of Driving by Local/SH Drivers

The analysis of costs and benefits assumed that the 11th hour of driving allowed under Option 1 was not used by local/SH drivers, on the basis of our understanding these operations and data that corroborated this understanding. We assumed, implicitly, that the few cases in which compliant drivers in local operations reported driving more than 10 hours in a tour of duty were erroneous: either regional drivers were classified as local because they returned to home base every night, or because non-driving time (e.g., during deliveries) was classified as driving for the convenience of the driver in keeping the log.

It may be, however, that this implicit assumption is incorrect, and there would be some impact on local/SH drivers from the elimination of the 11th hour. Taking the FMCSA survey data at face value, and assuming that 5 percent of all local/SH tours of duty exceeded 10 hours of driving, we estimate that Option 2 would reduce local/SH productivity by about 0.35 percent. Estimating the costs of this productivity impact using the same approach as for LH operations resulted in an estimated cost impact of about $100 million per year, which is less than a tenth of a percent of total local/SH revenues. Safety benefits would amount to less than $20 million.

6.7.3 Uncertainty about Fatigue-related Crashes

Because of the difficulty of identifying the causes of crashes, there is considerable uncertainty about the percentage of crashes that can be attributed directly or indirectly to fatigue. The 2003 RIA included a sensitivity analysis showing the effects on the benefit estimates of substantial changes in baseline estimates of fatigue-related crashes. A similar sensitivity analysis would show benefit estimates for Option 2 as high as $391 million and as low as $130 million, for baseline fatigue risk estimates of 15 and 5 percent, respectively, in place of the 8.15 percent value used for the 2003 RIA.

6.7.4 Compliance Rates

As noted earlier in this RIA, the baseline for the 2005 RIA analysis is the current operating environment (the 2003 rule), assuming full compliance with existing regulations. The baseline for the 2003 RIA was the operating environment at that time, or the pre-2003 rule, assuming full compliance by motor carriers with those regulations. The 2003 RIA also considered the effects of incomplete compliance in the baseline, relative to the full compliance baseline, but did not attempt to assess the possible degree of non-compliance with the option that was selected (and which is very close to Option 1 in this analysis). The supplemental (incomplete compliance) analysis performed as part of the 2003 RIA was performed due to the relatively broad scope and novelty of the three alternative regulatory packages considered as part of that rulemaking. As such, analyzing the economic impacts of the 2003 rule options from an alternative (incomplete compliance) baseline was appropriate. In contrast, the regulatory options considered as part of the 2005 HOS rulemaking were much less sweeping in nature. Given that the range of 2005 rule revisions were much less sweeping, FMCSA concentrated its analytical efforts on conducting a series of sensitivity analyses described above. FMCSA believes this more finely-grained (sensitivity) analysis was more appropriate here, given the relatively limited scope of the changes considered here.

APPENDIX (I) INDUSTRY DATA

(I).1 REGULARITY IN TL SERVICE

The percentage of TL service that is regular in character was estimated from three sources: conversations with Schneider staff; interviews conducted by George Edwards with eight TL carriers[55]; and the field survey conducted.

Schneider conversations: These suggest that something better than 50 percent of that firm's operations are regular.

Edwards interviews: The data from interviews with eight TL companies, weighted by company size (number of tractors), show 33 percent of truck-miles in regular operations.

Field survey: We considered a driver to be in regular operation if he had three or more weekends at home in a month. On that basis, 41 percent of apparently compliant [56] drivers were in regular operations. We further tested this by looking at times for starting and ending daily work for this group. This test showed a very strong tendency for drivers from the regular set to start and finish at the same time each day—further confirmation of regular operation. Start and finish times for the random drivers showed no consistent patterns at all—a clear sign of non-regular operation.

The following table shows our three data points for percentage of regular operations in TL service.

Exhibit (I)-1
Regularity in Truckload Service

	Regular Percentage
Schneider	>50
Eight TL Firms	33
Field Survey	41

On the basis of these findings, we have used 40 percent for our estimate of regular TL service. There is some reason to think this estimate is low. Our criterion for regular drivers in the field survey may be too narrow. It is undoubtedly the case that some drivers have regular runs that keep them out for one to three weeks. Further, the field survey and the Edwards interviews reflect relatively small TL concerns (by design in the case of the interviews). Most TL companies try to get as much regular business as they can, and there is every reason to believe that the largest companies are the most successful in this regard. Their size and reach enable them to accommodate the demands of very large manufacturers and distributors.

55 George Edwards is one of our team of industry experts.

56 We considered drivers as non-compliant if they recorded more than 11 hours of driving or 14 hours on duty in a tour. These anomalies could reflect errors in log keeping or other record keeping.

(I).2 INDUSTRY EXPERTS

The following individuals comprise the informal team of industry experts with whom we frequently consulted on many aspects of trucking-industry operations. With some of these people, we met face to face on two occasions for discussion of industry practice. We consulted them frequently by telephone and e-mail.

Michael Belzer, Wayne State University
Stephen Burks, University of Minnesota
George Edwards, trucking consultant
John Nienow, Schneider National
Donald Osterberg, Schneider National
Daniel Pierce, Schneider National
John Siebert, Owner Operator Independent Driver Association

Professors Belzer and Burks, and Mr. Edwards were paid consultants to FMCSA. We contracted for the services of Professors Belzer and Burks through Sound Science, Inc.

(I).3 ESTIMATION OF VEHICLE MILES OF TRUCKS FROM 10,000 TO 26,000 POUNDS WITHIN 150 AIR MILES OF THEIR HOME BASES.

In order to estimate the effects of a rule change for trucks in this size class, it is necessary to estimate truck-miles of operations of these vehicles within 150 air-miles of their home bases. Base is defined as the place where the truck is parked when not in service and from which the driver starts at the beginning of his work day and to which he returns at the end of it. It could be, for example, a factory, warehouse, office, trucking terminal, or residence. This estimate is based on the Vehicle Inventory and Use Survey (VIUS) in the 2002 Economic Census. Exhibit (I)-2 below shows the distribution of VMT of medium and light-heavy trucks across the operating-range intervals specified in the VIUS.[57] Operating range is a distance from home base beyond which the driver does not usually go in his normal operating pattern.

Exhibit (I)-2
VMT (millions) in Primary Range of Operation

Range (miles)	VMT	Percent
0-50	19,581	62%
51-100	6,416	20%
101-200	2,199	7%
201-500	1,837	6%
> 500	1,298	4%
Total	31,331	100%

Source: 2002 VIUS, Table 6, p. 47.

In order to go from these numbers to our VMT estimate, two further steps are required. Since the VIUS data do not directly give us mileage for an operating range of less than 150 miles, we must

[57] Census definitions: Medium trucks are from 10,001 to 19,500 pounds, and light-heavy trucks are from 19,500 to 26,000 pounds.

assign a fraction to the mileage in the 101-200 range to the 101-150 range. Also, the data in Exhibit (I)-2 understate total mileage because not all respondents answered the range-of-operation question.

We believe 75 percent of the VMT in the 101-200 range are in the 101-150 range. This is because the operations of these vehicles are heavily concentrated in the shorter ranges. As the operating range is extended past 100 miles, a smaller share of VMT is added with each increment in operating range. As the table shows, 62 percent of VMT are inside 50 miles; going out to 100 miles adds another 20 percent; and the 100-mile extension to 200 miles adds only another 7 percent. Therefore, it is reasonable to assume that the preponderance of the VMT in the 101-200 band are inside 150 miles from home base. In this context, we believe that 75 percent of these VMT can be prudently assigned to the 101-150 range. On this basis, the data in Exhibit (I)-2 yield an estimate of 27,646 million VMT within 150 air miles from home base for trucks in this size range.

This estimate must be adjusted upward to allow for the respondents who did not answer the range-of-operation question. For this purpose, we assume that the distribution of mileage over the operating range is the same for those who did not report it as those who did. Total mileage attributed to those who did not report range of operation is 6,085 million.[58] Total mileage for those who did report is 31,331 million. Since 6,085/31,331 = 0.194, we adjust upwards by this factor; 1.194 x 27,646 = 33,015. We may round this to 33 billion VMT.

One more difficulty with these data must be addressed. The entries in Exhibit (I)-2 are under the heading, Primary Range of Operation. "Primary" refers to the range in which a respondent's vehicle runs most of its miles. On the survey form, the respondent enters estimated VMT for each operating range; if the form shows 60 percent of a vehicle's VMT in the 101-200 range, *all* of its VMT is assigned to that range in Table 6. Therefore, some of the VMT shown in Table 6 in the 101-200 range actually was in some other operating range, whether shorter or longer. To the extent that some of the actual VMT was in shorter ranges (<101), we are not concerned; our goal is to estimate all VMT in ranges of less than 150 miles. To the extent that VMT in the 101-200 range in Table 6 was actually in ranges greater than 200 miles, we do have a concern.

The question is really whether the VMT distribution over the ranges by the "primary" method is significantly different from the distribution that results from assigning a respondent's VMT according to what is actually shown on the form. Table 8 of VIUS shows mileage in operating ranges as actually reported but only for all trucks and all trucks except light trucks. We can, however, compare the mileage distribution according to the "primary" method from Table 6 with the reported distribution in Table 8 for all trucks except light trucks. These distributions are quite different from that for the 10,000-26,000 pound trucks we are studying, because it includes the heaviest trucks whose use entails far more long-range operation than does any other class of truck. Nonetheless, if the distributions for all-except-light trucks are similar, we have reason to

[58] The unreported mileage is in two categories. not reported and not applicable. In the former case, respondents simply did not fill out the range-of-operation part of the survey form but reported total mileage. In the latter case, respondents owned vehicles for less than a full year; their total mileage was adjusted upward to allow for this but was not distributed over the operating ranges. VMT not reported was 6,013 million and not applicable was 72 million.

accept the estimates obtained from the data on primary ranges. This comparison is shown below in Exhibit (I)-3.

Exhibit (I)-3 Distribution of VMT (millions) over Operating Ranges for All-except-light Trucks				
Range (miles)	**Primary VMT**	**Percent**	**Actual VMT**	**Percent**
0-50	41018	35%	38231	33%
51-100	19499	17%	22238	19%
101-200	12133	10%	14286	12%
201-500	17842	15%	17539	15%
> 500	27075	23%	25016	21%
Total	117567	100%	117310	100%

We see that the percentages across the operating ranges are very close to the same. Assignment of VMT to the ranges on the basis of the "primary" method gives us no reason to set aside our estimate of 33 billion VMT inside 150 air miles from home base for 10,000-26,000 pound trucks.

(I).4 INTENSITY OF EFFORT—REGULAR VS. RANDOM OPERATION

In the following table, based on field survey data, we compare intensity of effort as between regular and random operation. For the purposes of this analysis, FMCSA defined an intense-effort driver as one who uses the 11th hour at least twice in a month and who works 65 hours in seven days at least once in a month. We present data for both compliant and non-compliant drivers and for all drivers in the survey. (We label as non-compliant those drivers in the field survey who logged more than 11 driving or 14 work hours in a tour of duty. Of course, these might reflect some errors in log entries.)

Exhibit (I)-4 Relative Intensity of Effort—Regular vs. Random Percentage of Intense-effort Drivers			
	Regular	Random	Combined
Compliant	**19%**	**39%**	**31%**
Non-compliant	**68%**	**88%**	**84%**
Combined	**31%**	**65%**	**55%**

NOTE: These data represent for-hire OTR truckload drivers.

In the following table, based on the FMCSA field survey data,we see that intensity of effort is greatest among random drivers and among non-compliant drivers. Of random drivers, 65 percent show intense effort; among all non-compliant drivers, 84.0 percent show intense effort. We note that the relatively high intensity of effort shown in Exhibit (I)-4 for random drivers is heavily influenced by the definitions of regular operation and intense effort that we used with the field survey data. We defined regular drivers as those who had three or more instances in a month of two consecutive days off, i.e., drivers who do not work on weekends. However, relatively few such drivers will work 65 hours in a seven-day period. It should be noted that when we measured intensity of effort by hours worked in a tour of duty, there was little difference between random and regular drivers (Exhibit 2-3 in section 2.1.4)

(I).5 SPLIT SLEEPER PERIODS—REGULAR VS. RANDOM

The following table, based on data from the field survey, compares incidence of splitting for regular and random drivers.

Exhibit (I)-5
Percentage of Drivers Splitting

	Regular	Random
Drivers Logging at Least One Break as Split	**36%**	**51%**
Drivers Actually Splitting at Least Once	**29%**	**35%**
Tours of duty with actual splitting	**3.5%**	**5.9%**

NOTE: These data represent for-hire OTR truckload drivers.

Periods "logged as split" means hours were entered for split sleeper periods. In many cases, however, ten or more hours were entered in "split" periods. "Actual" splitting means two sleeper periods added to at least ten hours and neither was less than two hours or more than ten.

Once we focus on actual splitting, we see that neither group splits very often, and the regular drivers appear less likely to split than random drivers.

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APPENDIX (II)DETAILS OF MODELING OF CARRIER OPERATIONS

Definition of Regions

As one of the user-defined assumptions, the model can simulate one or more of four continental U.S. regions: Northeast, Midwest, West, and South. The Northeast region includes Connecticut, Delaware, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont. The Midwest region includes Illinois, Indiana, and Ohio. The West region includes Arizona, Arkansas, California, Colorado, Iowa, Idaho, Kansas, Louisiana, Minnesota, Missouri, Montana, Nebraska, New Mexico, Nevada, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming. The rest of the states constitute the South region.

Default Assumptions

In addition to the assumptions that can be revised by the user, the model has a number of default assumptions, detailed here:

- *Loading and Unloading Time* The time required for loading and unloading the vehicle is based on a random draw from a normal distribution with a mean of 2 hours and a standard deviation of 30 minutes. Further, we have assumed for computational ease a minimum loading and unloading time of 30 minutes, with the concurrence of industry expert opinion for reasonableness.

- *Pick-up Day of Week* The distribution of the day of the week for shipment pick-ups is based on a report by Reebie Associates[59], which determined the following patterns from data available from truckload carriers:

Exhibit (II)-1: Day of Week Patterns

Day of Week	Percentage
Sunday	0.8%
Monday	17.8%
Tuesday	19.7%
Wednesday	19.9%
Thursday	19.0%
Friday	19.5%
Saturday	3.3%

Exhibit (II)-1 shows that pick-up days are basically evenly distributed for the weekdays while the weekends are rarely used. The simulation of the pick-up day for a given shipment in the model is based on the percentages shown above. However, we have limited the alternatives so that the available possibilities for the next shipment pick-up are the same day as the just-completed drop-off and the two days immediately subsequent. For example, if the truck has arrived on Tuesday, the pick-up day choices for the next shipment would be based on the relative distributions for Tuesday, Wednesday, and Thursday.

[59] "Day-of-Week Motor Carrier Demand Patterns," Reebie Associates, June 12, 2002.

- *Delivery Day of Week* The scheduled delivery day of the week depends on the pick-up day of week and the travel time required to the delivery destination. The model calculates a simplified transit time from the origin to the destination as equal to the distance between the origin and destination divided by the average driving speed (default of 50 mph), and then doubled to allow for non-driving time (for breaks, etc.). Effectively, this makes trips feasible if the CMV operator spends at least 50 percent of the time after pick-up driving.

- *Pick-up and Delivery Windows* The pick-up and delivery windows represent the interval of time in which a pick-up or interval needs to be made. Based on research and input from industry experts, they are assumed to have the distributions shown in Exhibit (II)-2:

Exhibit (II)-2
Distribution of Pick-up and Delivery Windows

Window size	Pick-up Window	Delivery Window
15 or 30 Minutes	11%	44%
AM or PM	37%	33%
Whole Day	53%	22%

If the whole day is noted as the pick-up/delivery window, the CMV operator is able to pick-up/drop off any time during the day. Similarly, we assumed that the AM window is from 12 midnight to 12 noon while the PM window is from 12 noon to 12 midnight. For the shorter 15 minute and 30 minute windows, we assigned the distribution of pick-up/delivery windows as suggested by the industry experts following the distribution of all actual pick-up and delivery times. The pick-up and delivery window distributions for the 15 and 30 minute windows are shown in Exhibits (II)-3 and (II)-4. Within each of these ranges, the actual window was randomly assigned (using a uniform distribution) to a time increment commencing within the range.

Exhibit (II)-3
Distribution of Pick-up Hours for 15 or 30 Minute Windows

Pick-up Hour	% of Shipments
22:00-10:00	60%
10:00-14:00	30%
14:00-22:00	10%

Exhibit (II)-4 Distribution of Delivery Hours for 15 or 30 Minute Windows	
Delivery Hour	**% of Shipments**
05:00-08:00	40%
08:00-14:00	40%
14:00-21:00	10%
21:00-05:00	10%

Model Operation Note

In a few cases, none of the 20 origin-destination (O-D) pairs that the CMV operator faces are feasible. For example, if a CMV operator arrives at the destination on late Friday, then all 20 pairs presented to the operator may be infeasible since the model draws very few Saturday and Sunday pick-ups (and may pick all 20 pickups for earlier in the day on Friday than the driver is available). In such cases where no origin-destination pair is feasible, the model allows the driver to have an extra day of pick-up (Monday) so the driver can choose from a feasible set of choices. Then, the model simulates all 20 O-D pairs instead of only the top seven, to ensure that the CMV operator chooses the shipment with the highest utility.

Order Sets

The process of obtaining a representative sample of the US truck transportation industry's movements began by obtaining data sets containing the total tons shipped to and from every county in the country, sorted by FIPS code[60]. It was decided to base the sample on the total tons shipped to and from each county to best represent the number of truckload moves. The shipments to and from each county were combined to create a table relating each county to the total tons shipped associated with it. This data set provided 3,141 data points from which to create a sample. First, a sample size of 1,000 was established, to speed model computation time and assuming that quantity to be more than sufficient to represent industry movements for the purposes of the model. Next, those counties and areas located outside the lower 48 states were removed from the potential sample, as their geographic circumstances would not permit modeling within this framework. This step reduced the number of FIPS codes used as potential data points to 3,109. Then, counties were sorted by total tonnage, and the 194 counties whose movements made up 60 percent of total goods shipped were placed in the sample. The remaining 2,915 counties were assigned random values between 0 and 1, and those with the 806 largest random numbers were included in the sample to complete the set of 1,000.

Treating the sample set as a closed system, statistical software was then used to calculate the probability of a shipment going from each FIPS origin to each separate FIPS destination, ignoring the probabilities associated with the FIPS areas outside the sample. Because the 2,915 smaller counties were now under-represented in the sample, an imbalance was present in the O-D probabilities. In order to correct this imbalance, the proportion of total tonnage of low-volume counties in the data set relative to the tonnage of those low-volume counties used in the sample

[60] FIPS codes generally represent counties, parishes or districts. The term county is used interchangeably herein to also represent FIPS code areas, parishes and districts.

was calculated, which was roughly equal to 3.76. The origin-destination probabilities in cases where the destination was a low-volume county were then multiplied by that proportion.[61] This step effectively made the low-volume counties that were randomly selected for the sample stand in for all low-volume counties in the data set.

After this rebalancing of the sample's representation, the sum of the destination county probabilities for each individual origin county did not precisely equal one. In order to recalibrate the probabilities to achieve a workable model, each origin-destination combination's initial value was divided by the initial sum of the origin county's values. These new probability values were then summed to result in a total probability for each origin county of one.

Utility Function

The specific formulation and assumptions for the utility function are as follows:

Total Utility = Revenue - Cost – AwayFromHome Penalty + HOSStatusPremium
where

Revenue = Fixed shipment revenue + RevenueMiles from shipment pick-up to shipment drop-off * Revenue/mile) + ServicePremium revenue

where

Fixed shipment revenue = $120
RevenueMiles = Miles from shipment pick-up to shipment drop-off
Revenue/mile = $1.18
ServicePremium revenue = $25 per pick-up or drop-off with a15-minute or 30-minute time window

and

Cost = (OperatingCost/mile * VehicleMiles) + (Cost/clock-hour * ClockHours)

where

OperatingCost/mile = $1.13/mile for employee drivers paid per mile
VehicleMiles = Miles from previous drop-off to next destination drop-off (i.e., includes "deadhead" miles to shipment's pick-up)
Cost/clock-hour = $5.40/hour for employee drivers paid per mile
ClockHours = Total hours (duty and non-duty) from previous drop-off to next destination drop-off (i.e., includes "deadhead" time to shipment's pick-up time)

and

61 Shipments to high-volume counties did not need adjustment as they were fully represented in the sample.

AwayFromHome Penalty = $V * (max (0 , 1 - ((DaysAway/W)^X * (DestDistAway/Y)^Z))

where

V = $10.00
W = 14 days
X = 2 (exponential parameter for time away from home)
Y = 500 miles
Z = 1.25 (exponential parameter for destination's distance away from home)

and

HOSStatusPremium = HoursBeforeRestart * Net revenue per duty hour

where

HoursBeforeRestart = Expected hours drivers will have remaining in 70-hour HOS work period before the 34 or 58 hour "restart" rest period

Net revenue per duty hour = $2.00 (based on expert opinion derived from revenue data presented in the *Blue Book*).

Algorithms

The details of the algorithms used to carry out some of the specific model components. are detailed below:

Destination Algorithm

The shipments' origins and destinations are based on recent empirical data regarding the actual probabilities of commercial truck movement from county to county in the continental United States. As explained in the order sets section (3.2.3), the available data provides the probabilities of shipment movements among the representative counties. Thus, the destination county is drawn based on the distribution of shipment movements from the origin county to potential destination counties. Specifically, when the destination algorithm is initiated, the model generates a random number between 0 and 1 and the model sequentially adds up each of the individual shipment probabilities associated with the origin county to potential destination counties until the cumulative sum is greater than the randomly generated number. Once the cumulative sum exceeds the randomly generated number, the model chooses the particular destination county that marginally increases the cumulative sum to be greater than the randomly generated number as one of the 20 origin-destination pairs.

Load Choice Algorithm

As explained in the operation section of Chapter 3 (3.2.2), the model simulates the top seven origin-destination pairs among the 20 pairs. The choice algorithm allows the user to see actual behavioral pattern of the driver in each of 15 or 30 minute time slots as the vehicle hypothetically would “move” from the origin terminal to the destination terminal. The algorithm also ensures the driver complies with all of the HOS regulations.

The algorithm starts each time increment with the decision of whether to rest or not. The CMV operator always decides to rest upon reaching the limit on driving hours or duty hours per day or the limit on cumulative duty hours in the last 8 days.

When the CMV operator decides not to take a rest, it has to decide whether to drive, load, unload, or just wait. The CMV operator waits[62] if it has driven four consecutive hours and still has more than one hour of driving left until the destination. If it has not reached the limit on driving hours and has not arrived at the destination, it chooses to drive. Once it arrives at the destination and is not resting, it either unloads or waits. To wait is counted as duty time, even though the truck is not moving, since the CMV operator is not fulfilling the HOS criteria for rest time. In these cases, the driver waits until it is within the delivery window and then unloads. Similarly, when it arrives at the pick-up terminal and is not resting, it waits until the time is within the pick-up time window and then loads the shipment.

The decision to drive, load, or unload is overridden when the CMV operator reaches the limit on the cumulative duty hours in the last 8 days. Then, the CMV operator automatically rests until its restart rest hours are met, or until the last 8 days included less than 70 hours on duty.

Schedule Algorithm

The schedule algorithm includes all the decision-making procedures within the choice algorithm. The schedule algorithm writes the selected origin-destination pair to the output table.

Feasibility Algorithm

In order to reduce the computing time for the model, we simulate seven origin-destination pairs among the 20 pairs that the CMV operator is presented with. The feasibility algorithm screened out the 13 pairs that would lead to the lowest utility. The algorithm calculates the travel time it takes to get to each pick-up terminal. Then it compares the travel time with the pick-up time and pick-up window of each origin-destination pair to check feasibility. Because the CMV operator is constrained by the limits on driving hours per day, a 4 hour drive to the next destination may take more than 4 hours. For example, it takes only 4 hours if the operator has at least 4 hours left on its daily limit on driving hours, but it would take 14 hours if the operator already had reached the limit on the driving hours per day and has to rest for 10 hours. Thus, the feasibility algorithm eliminates infeasible O-D pairs.

Longer Restart Rest Period Algorithm

When the CMV operator reaches the limit on cumulative duty hours in the last 8 days, the operator takes a restart rest of the required minimum hours (see user-defined inputs). This rest also re-set the cumulative count toward the limits. In other words, if the cumulative driving hours are at 5 hours, taking the restart rest hours re-sets the cumulative driving hours to 0 hours.

[62] Effectively, this represents the driver taking a break without fulfilling criteria for HOS “rest”, and thus counts as duty time but not driving time.

In actuality, many commercial truck drivers take longer restart periods than are actually required, presumably in order to start their next working period in the morning or at a convenient or accustomed time. Therefore, the model reflects the longer restart rests by imposing the following pattern of restart rests:

Long – Short – Short – Long – Short – Long – Short – Long

The "Long" restart period means that the CMV operator takes longer restart rests by resting until 7 AM of the next day in addition to the regular restart rest of 34 or 58 hours. The "Short" restart period means that the CMV operator takes regular restart rest of 34 or 58 hours. The first restart period is "Long" so the CMV operator takes extra rest until 7 AM the next day. The second and third restart periods are regular restart rests, so it starts working as soon as the restart hours are up. Similar to the first restart, in the 4^{th}, 6^{th} and 8^{th} restarts, the CMV operator takes extra rest until 7 AM the next day in addition to the 34 or 58 restart rest hours. The fifth and seventh restart periods are regular restart periods. This pattern of restart periods gets repeated so the driver takes two consecutive long rests as it turns from the 8^{th} restart to the 9^{th} restart.

Break Time Algorithm

In order to make the model more closely reflect the driving patterns of actual truck drivers, a break period of either 30 minutes or one hour is imposed whenever the CMV operator drives four straight hours with more than one hour left until the destination. If the CMV operator has equal to or less than one hour of driving left until the destination, the break period is not imposed since actual truck drivers would skip the break and continue driving.

The decision to break for 30 minutes or one hour is based on a random number generation with a 50 percent chance of each. According to DFACS survey, commercial truck drivers typically stopped for a break after 4 to 5 hours, and typically rested 30 to 60 minutes, with a median of 45.

Split Sleeper Berth

The model initiates the split sleeper berth algorithm whenever the CMV operator arrives at the pick-up or destination terminal and still has some time until the pick-up/delivery hour window. Specifically, if the minimum split sleeper berth is 2 hours and the daily rest is 10 hours, then the CMV operator takes a split sleeper rest if its waiting time at the pick-up or destination terminal is between 2 and 8 hours. If it needs to wait less than 2 hours, then it uses its duty time to wait for the shipment and if the wait is more than 8 hours, it uses its 10-hour rest to wait for the shipment.

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APPENDIX (III)
REVIEW OF SAFETY LITERATURE

(III).1 INTRODUCTION

The purpose of the literature review was twofold: to identify and summarize material published or identified since the preparation of the 2003 RIA, and to identify material that has a bearing on the specific issues considered in proposed revisions to the 2003 HOS regulations. The revisions were specifically concerned with maximum driving time between rest periods, the issue of team driving where the driver works a series of short driving and rest periods and the effectiveness of long "weekend" breaks on accumulated sleep deficits. Much of the material is drawn from a literature survey commissioned by FMCSA specifically for this analysis, supplemented by relevant material identified by an FMCSA contractor as the work progressed.

The review is organized into broad subject headings as follows:

- Sleep and Performance Modeling;
- Survey-Type Studies of Truck Driver Fatigue and Performance;
- Instrumented and/or Laboratory Studies of Driver Fatigue and Performance; and
- Truck Crash Risks and Costs.

A brief summary is provided for each paper or report, containing a description of the study and principal findings relevant to the HOS analysis.

(III).2 SLEEP AND PERFORMANCE MODELING

(III).2.1 Steven R Hursh, Daniel P. Redmond, Michael L. Johnson, David R. Thorne, Gregory Belenky, Thomas L. Balkin, William F. Storm, James C. Miller and Douglas R. Eddy "Fatigue Models for Applied Research in Warfighting", Aviation Space and Environmental Medicine, Vol. 75, Number 3 Supplement, 2004.

Description of Study

This paper describes the development and application of a comprehensive model for estimating the performance of personnel as a function of work and sleep schedules. The sleep and performance model, called the SAFTE model (Sleep, Activity, Fatigue and Task Effectiveness) is an outgrowth of an ongoing sleep and performance research conducted at the Walter Reed Army Institute of Research. Earlier, the WRAIR had developed a Sleep Performance model (WRAIR-SPM) based on laboratory tests of vigilance performance as a function of sleep and work schedules. This model was refined in a cooperative effort of several research organizations, and incorporation of research findings from a large number of sources to create the SAFTE model. This model incorporates two of the three main determinants of performance: circadian rhythm effects (both due to travel across time zones and due to the time-of-day of the working period) and sleep deprivation arising out of sleep and work schedules over the past few days. The model does not include time-on-task (TOT) effects. The SAFTE model has been incorporated into a working tool called FAST (Fatigue Avoidance Scheduling Tool) that provides a user-friendly interface to the SAFTE model for evaluating alternative schedules.

Modeling Approach

The core concept behind the SAFTE model is that of a sleep reservoir which individuals draw upon while awake and which is replenished by sleep. The overall structure of the SAFTE model is described below.

Alertness or performance is a function of three inputs:

- The amount of depletion of the sleep reservoir – research shows performance declines to the low level of 25% of that of a fully rested individual after 72 hours continuous wakefulness. A linear relationship between performance and sleep debt is used, although some research results suggest a non-linear relationship. Both the slope and shape of relationship can vary with the test task used to assess performance.

- Sleep inertia effects. Full wakefulness is not attained instantly on awaking. Instead there is a period, typically on the order of 1 to 2 hours, depending on sleep intensity and the current status of the sleep reservoir, during which performance recovers to a peak value, after which the normal decline with reservoir depletion resumes.

- Circadian rhythm effects. As discussed in Section 5.1.1, the circadian cycles affect alertness as a function of time of day and the individual's sleep/waking cycles over the past several days.

The model applies the results of numerous research studies of each effect to provide a continuous estimate performance levels over time. In principal, the model is not limited to one specific performance measure (such as the Psychomotor Vigilance Test (PVT) measure used in both this and the original truck HOS analysis), provided there is a sufficient research base to establish the relationships between task performance and the status of the sleep reservoir.

Replenishment of the sleep reservoir also depends on multiple inputs, as follows:

- Length of sleep. A non-linear function exists between the length of sleep and the amount of replenishment. The per-hour replenishment is less for the first three hours of sleep than later in the sleep cycle. The model also incorporates a factor for fragmented sleep, to quantify the reduction in sleep effectiveness due to frequent wakening, such as from external noise and vibration or a sleep disorder.

- Reservoir depletion level. Generally the lower the sleep reservoir, the greater the restorative effect of sleep. The term sleep intensity is used to quantify this effect.

- Circadian rhythm. Sleep is more effective (higher sleep intensity) around the low points in the circadian rhythm.

As with performance estimates, the SAFTE model applies the results of numerous research studies to estimate reservoir replenishment for a given period of sleep.

The authors conclude by identifying a number of areas where there are unexplained contradictions or anomalies in the available data, and where further research would be useful.

One key area is the relationship between the performance metric and the actual demands of a specific task. In the HOS analyses, a relationship was developed between PVT and crash risk from truck driving simulator tests. Similar relationships are needed for other tasks, both to identify the most appropriate measure for a specific task and to establish a relationship for use in practical applications of the model.

(III).3 SURVEY-TYPE STUDIES OF TRUCK DRIVER FATIGUE AND PERFORMANCE

(III).3.1 Arnold, P.K., Hartley, L.R., Hochstadt, D., and Penna, F. "Hours of work, and perceptions of fatigue among truck drivers." (1997). Accident Analysis & Prevention, 29 (4) 471-77.

Description

This paper summarizes the results of a survey conducted with 1,249 truck drivers and 84 management representatives of transport companies. Data was collected in an Australian state which, at the time of the survey, did not restrict driving hours for heavy haulage drivers. Regulations were being discussed to limit driving to 14 hours in any 24-hour period, and restricting driving hours over the week to 72 hours. The aim of the study was to obtain information about hours of work and sleep from drivers operating in an unregulated environment. Drivers were asked to provide details about their driving and non-driving work schedules and the amount of sleep they had obtained in the past week. They were also asked to give an hour-by-hour record of activities, feelings of fatigue, and encounters with dangerous events over the 24 hours prior to the interview. Drivers and company representatives were interviewed about their perceptions about fatigue (e.g., factors perceived to be related to fatigue, causes, management) and whether they felt fatigue was problematic for truck drivers. A definition of fatigue was not provided. The authors concluded the paper by comparing their data on unregulated drivers' perceptions about fatigue to those reported by Williamson et al. (1992) for mainly regulated drivers.

Relevant Findings

- In a 24 hr period approximately 38% of drivers exceeded 14 hours of driving and 51% exceeded 14 hours of driving plus other non-driving work
- Approximately 17% of unregulated drivers exceeded 72 hours of driving in the week. When non-driving work is added, 30% worked in excess of 72 hours.
- Approximately 12% of drivers reported less than 4 hours of sleep on one or more working days in the week preceding the interview. These drivers are likely to be operating their vehicles while having a significant sleep debt.
- Approximately 20% of drivers who reported having less than 6 hours of sleep before starting their current journey reported 40% of the hazardous events
- Twelve percent of drivers who reported having had a crash in the previous 9 months identified fatigue as a contributing factor
- Five percent of the unregulated drivers reported having experienced a hazardous, fatigue related event, such as nodding off, on their current journey."

- 20% of drivers who reported having had less than 6 hours sleep reported 40% of the hazardous events."
- Many drivers and company representatives reported fatigue to be a problem for other drivers but considered themselves or their companies' drivers to be relatively unaffected by fatigue
- The authors concluded the paper by comparing their data on unregulated drivers' perceptions about fatigue to those reported by Williamson et al. (1992) for mainly regulated drivers. The results suggest that unregulated drivers perceive that fatigue is a problem for themselves less frequently than regulated drivers (10% versus 28-35%). Similarly, fewer unregulated drivers considered fatigue to be a general industry problem than did regulated drivers (39% versus 78%). These differences in frequency ratings may be due to differences in the attention paid to fatigue as a safety problem in regulated and unregulated states.

(III)3.2 Feyer, A.M., Williamson, A., Friswell, R. "Balancing work and rest to combat driver fatigue: An investigation of two-up driving in Australia." (1997). Accident Analysis & Prevention, 29 (4) 541-53.

Description of Study

This study was designed to examine the nature and impact of two-up driving operations on fatigue. Long-haul truck drivers were measured on a 4,500 km round trip. The driving operations of single driving (i.e., a solo driver) and two-up driving (i.e., pair of drivers operating a truck continuously, alternating work and rest) were compared.

A "between groups" design was used for this study, in which each participant only drove one evaluated trip using his regular operation –either two-up or single. Drivers were asked to drive a 4 to 5 day round trip of approximately 4500 km. in Western Australia. At the time of the study, the state of Western Australia did not have enforced driving hours regulations. Twenty-two of the 37 participants regularly worked two-up operations on the selected route and 15 regularly worked as single drivers. A variety of measures were used to assess drivers' fatigue and its effects such as heart activity, speed and steering wheel angles, auditory reaction time tasks, cognitive tests, and subjective measures of fatigue. Prior to starting their trip, participants were also asked to complete questionnaires about their general state of physical health, their lifestyle and their pattern of work/rest in week preceding study.

Relevant Findings

"Irrespective of driver operation, fatigue increased for drivers on long-distance trips typical of remote zone driving."

- "Two-up drivers reported and showed evidence of greater fatigue than single drivers before the trip started and appeared to be more fatigued overall for most of the trip."
- "Over the homeward leg of the trip, two-up drivers reported no change in the level of fatigue, with fatigue having peaked at mid trip. For single drivers, in contrast, fatigue peaked at the end of the homeward leg, despite considerable recovery at mid trip."

- While overall the two-up group showed greater fatigue compared to single drivers, some ways of doing two-up (e.g., overnight stationary rest, shorter trip duration) were less fatiguing than single driving.
- Two-up drivers started the trip more fatigued and this "disadvantage remained for most of the trip"… "but was most marked over the first leg of the trip where fatigue for two-up drivers continued to worsen at a greater rate than for single drivers."
- "… where work practices kept the fatigue under control, such as on shorter two-up trips and two-up trips incorporating overnight stationary rest, breaks were more likely to be helpful. In contrast, where fatigue was allowed to build-up, such as on single trips and on very long two-up trips without stationary rest, breaks did not provide relief once fatigue had accumulated."

- Overnight stationary rest for two-up drivers at mid trip, was associated with dramatic reductions in fatigue levels after the break, and allowed these drivers to finish the trip with the lowest levels of fatigue of any group, including single drivers. Two-up drivers who had no stationary rest, but had the shortest trip duration of any group showed an overall increase in alertness over the homeward journey, finishing the trip at roughly pre-trip fatigue levels."

- Working hours regulations for long distance drivers are primarily based on limitations to periods of driving and rest within a trip, largely in isolation from overall scheduling patterns. In contrast, the current findings strongly suggest that effective management of fatigue involves considerations of the whole pattern and timing of work and rest

(III)3.2 Hakkanen, H. and Summala, H. (2000). "Driver sleepiness-related problems, health status, and prolonged driving among professional heavy-vehicle drivers." Transportation Human Factors, 2(2), 151-171.

Description of Study

This paper summarizes the results of a survey conducted with 567 Finnish professional drivers who responded to a questionnaire, out of 2,000 randomly-chosen drivers who were invited to take part. The drivers had 5 different work descriptions, and were part of a non-political organization promoting truck drivers' interests. The mailed questionnaires were completed anonymously. The main purpose of this survey study was to examine the relation between truck drivers' health and sleepiness-related problems while driving. In addition, factors most likely to predict increased driver sleepiness were identified. Furthermore, frequency of non-compliance with the driving-hours regulations (in terms of driving more than 10 hours) and drivers' comprehension regarding the suitability of the regulation were surveyed. In Finland, truck driving hours are subject to control by EC regulation No. 3820/85, according to which the maximum driving time is 10 hr and the resting time is 11 hours per each 24-hr period. Previous studies had indicated that all drivers do not follow the limits set by the regulation.

The questionnaires requested information on the drivers' preceding 3 months' work, possible sleepiness-related problems at work and their opinions about maximum permitted driving times. In addition, they were also given parts of the Basic Nordic Sleep Questionnaire and the Epworth Sleepiness Scale to estimate the "prevalence of suspected sleep apnea syndrome and to collect data of driver's sleep history." Drivers were also asked questions about their self-perceived general health status and the occurrence of any chronic illnesses.

Relevant Findings

- "The results of the study indicated that approximately one third of all the drivers drive generally more than 10 hr, which violates the EC regulation."
- "More than 70% of the drivers felt that the maximum permitted driving hours should be at least 11 hr per a 24- hr period".
- Nineteen per cent reported having dozed off at least twice while driving, and 8% reported a near-miss situation due to dozing off during the past 3 months.
- "Sleepiness-related problems while driving appeared across all driver groups (i.e., long haul, short haul, bus drivers, drivers transporting dangerous goods, drivers transporting wood), including drivers transporting dangerous goods and bus drivers, and were strongly related to prolonged driving, sleep deficit and drivers' health status. The effects of the latter factors were interactive and cumulative: Frequent sleepiness-related problems occurred in more than one half (52.3%) of the "drivers with the combination of prolonged driving, sleep deficit, and lowered self-perceived health."
- The 10% of drivers who were suspected to have sleep apnea syndrome (note: screening through questionnaires only) reported having experienced significantly more frequent sleepiness-related problems while driving although they did not report a significant increase in the frequency of sleepiness-related accidents.
- Less healthy drivers were both significantly older and tended to work longer hours and report greater sleep deficits and more problems with alertness and sleepiness while driving. These differences extended particularly to drivers reporting chronic illness in the last three years.
- The evidence for a cause-and-effect connection between a chronic illness and sleepiness-related problems while driving was somewhat mixed. While "the univariate comparison between those with an illness and others suggested a marked difference in sleepiness-related problems," the "logistic regression analysis showed that when other relevant factors were controlled (e.g., age, driving time) the effect of a chronic illness was no more significant whereas perceived health status better explained sleepiness-related problems while driving." The authors suggested that this result might be partly due to the fact that the discovered illnesses were rather heterogeneous. Increased odds of having more frequent difficulties in remaining alert if the driver self-perceived as having no more than a satisfactory health.
- When all the relevant factors were controlled, shift type and driving time were the only work-related variables that significantly predicted more frequent difficulties in remaining alert ($p<.05$ and $p<.05$, respectively). The odds of having experienced more frequent difficulties increased by a factor of 1.85 if the driver had been driving a night or irregular shift and by 3.57 if the driver had been driving more than 17 hr (compared to fewer than 6 hr driving).
- The authors conclude that the results give unreserved support for regulating driving hours and increase concern of the connection between professional drivers' health status and sleepiness-related problems while driving.

- Drivers were more apt to have frequent difficulties remaining alert if they had been driving a night or irregular shift, or had been driving more than 17 hours.

(III)3.3 Morrow, P.C. and Crum, M.R. (2004) "Antecedents of fatigue, close calls, and crashes among commercial motor-vehicle drivers." Journal of Safety Research, 35 (1).

Description of Study

This paper summarizes the results of a survey of commercial motor vehicle drivers in 116 trucking firms. The purpose of the study was to identify factors (i.e., fatigue inducing and company safety management factors) relevant to the prediction of driving while fatigued, close calls due to fatigue, and actual crash involvement among CMV drivers engaged in intra- and interstate truck driving.

Thirty-two of the 116 firms in the study were top safety-performing firms, 53 from average firms and 31 from poor performing firms. Drivers were asked a number of questions about fatigue-inducing factors such workload, schedule regularity, difficulty finding rest places, adequacy of sleep, insufficient recovery, per cent of time loading/unloading. In addition, participants were asked about the perceived safety climate in their company. The authors formulated 11 perceived safety climate items (e.g., "Our Company makes driving safety a top priority") and asked drivers to record their level of agreement). Finally drivers were asked about their fatigue while driving (e.g., nodding off while driving, etc.,), as well as frequency of close calls and crashes.

The authors proposed three models to account for the variation in fatigue while driving, close calls due to fatigue, and crash involvement. Proposition 1 specified that fatigue-inducing factors would account for variation in these outcome measures. Proposition 2 specified that "company safety management practices should account for variation in the outcome measures, controlling for fatigue-inducing factors associated with truck driving work." Proposition 3 contended that "fatigue while driving accounts for variation in the frequency of close calls due to fatigue and crash involvement, after controlling for fatigue-inducing factors and company safety management practices."

Relevant Findings

- "Fatigue-inducing factors inherent in driving work and safety practices" (e.g., schedule regularity, difficulty finding a place to rest, adequacy of sleep when working, insufficient recovery, per cent of time loading/unloading, etc.,) "accounted for appreciable variation in driving fatigue (R squared =. 42) and close calls (R squared = .35), but not crash involvement." Self-report measures were used to assess fatigue (i.e., 3-item measure). Crash involvement was measured using the sum of two items: 1) reportable accidents (to the company) and 2) chargeable accidents that drivers had been involved with over the last 2 years.

- Approximately one-fifth of the drivers reported having one or more reportable accidents, and approximately 4% reported having chargeable accidents. The raw data was adjusted to account for exposure and expressed on a per 100,000 miles basis. Drivers with reportable accidents had between .32 and 6.41 crashes per 100,000 miles, while those reporting chargeable accidents had between .29 and 1.03 crashes per 100,000 miles. The measure exhibited a Cronbach alpha of .85.

- "Driving while fatigued accounted for incremental increases in the amount of variation in close calls, after consideration of inherent factors and safety practices."

- Safety practices (e.g., establishment of a strong safety culture, dispatcher scheduling practices, company assistance with fatiguing behaviors such as loading and unloading) have considerable potential to offset fatigue-inducing factors associated with truck driving work."

- While there is an assumption that employees will use off-duty time to engage in restorative activities, the insufficient recovery results reported in this study, led the authors to conclude that "drivers do not necessarily spend their non-work time in this manner". While drivers may not engage in job-related activities during their recovery periods, some drivers do engage in activities and sleep patterns that lead them to report back to work already fatigued. 47% of the drivers reported that they started the work week fatigue with some regularity. The authors note that the results "suggest that the potential misuse of off-duty time can be mitigated by the presence of a strong safety climate or enactment of policies targeted at fatigue-inducing activities (i.e., companies can act to reduce this problem)."

(III)3.4 Williamson, A., Feyer, A., and Friswell, R. (1996). "The impact of work practices on fatigue in long distance truck drivers." Accident Analysis & Prevention, Vol. 28, No. 6, 709-71

Description of Study

The aim of this Australian study was to investigate the relationship between staged driving and fatigue. Professional truck drivers completed a 12 hour, 900 km trip under each of three driving regimes – a relay (staged) trip, a working-hours-regulated one-way (single) trip, and a one-way (flexible) trip with no working hours constraints. All of the observed trips took place overnight.

The staged trip entailed driving from Sydney or Melbourne to the trip midpoint (Tarcutta), exchanging trucks or loads with a driver coming in the opposite direction, and then returning to the point of origin. "The single one-way trips involved driving directly from Sydney to Melbourne, and the flexible one-way trips involved driving from Melbourne to Sydney." "Under the regulations, drivers on single and staged trips were obliged to break for 30 minutes after each five hour period. Under the flexible regime drivers could choose to take breaks as often or as rarely as they needed with no constraint on the time taken to complete the trip." All of the observed trips took place overnight. Most trips began in the early evening and night between 16:00 and 23:59. The three driving regimes did not differ significantly in starting time. While, on average, the staged trips took longer to complete than flexible trips, the trip lengths differed by only 40 minutes. The study employed subjective (e.g., Stanford Sleepiness Scale, etc.), physiological (e.g., heart rate), and performance (e.g., speed, steering variability, reaction time, etc.) "measures to examine the relationship between the characteristics of staged driving and the development of fatigue.

Relevant Findings

- Although there was some evidence that fatigue developed differently within the three driving regimes (staged, single, and flexible), the levels of fatigue experienced by drivers increased markedly over all the trips

- Drivers tended to feel most fatigued on staged trips and least fatigued on single trips, however, this pattern was in evidence before driving commenced and post trip had not been modified by the intervening driving regime.
- "None of the regimes demonstrated any overall advantage in combating fatigue compared to the other regimes."
- It is clear from the findings that "even relatively short 12-hour trips are tiring, and that effective strategies for fatigue reduction need to be identified."
- The number of breaks taken increased across flexible, single and staged trips, suggesting an increasing need for rest as a function of driving regime. However, breaks were taken after similar periods of driving for the three trip types (Table 1). The longest driver period (4.5 hours) routinely occurred before the first break and the shortest drive period (2.5-3 hours) preceded the second break
- Pre-trip level of fatigue appears to be an important determinant of later fatigue. This raises questions about the ongoing work schedules under which long distance drivers operate, "and highlights the need to allow adequate rest and recuperation between trips and between blocks of trips to prevent chronic sleep loss and to reduce fatigue."

(III).4 INSTRUMENTED AND/OR LABORATORY STUDIES OF DRIVER FATIGUE AND PERFORMANCE

(III)4.1 Baas, P.H. (Transport Engineering Research New Zealand (TERNZ)), Charlton, S., and Bastin, G. (2000) "Survey of New Zealand truck driver fatigue and fitness for duty." 4th International Conference on Fatigue and Transportation, Fremantle, Western Australia.

Abstract

This study involved Interviews and simulator-based performance test conducted at depots, wharves, markets and other locations throughout the North Island of New Zealand throughout the day and night. The reported analysis covers results from the first 100 drivers.

The survey was conducted with 600 truck drivers at depots, markets, etc. around the North Island of New Zealand. Interviews focused on "driver demographic and work/rest patterns, drivers' attitudes towards fatigue, propensity towards daytime sleepiness, and a self-assessment of the driver's momentary level of fatigue." A simulator-based performance test of driving was also undertaken on adapted version of the commercially available truck operator proficiency system (TOPS). "In the course of its development, TOPS passed through several verification and validation stages resulting in a pass/fail criterion for driver performance." The performance test consisted of a standard driving task, a dual-axis sub-critical tracking task, and a tertiary or side-task requiring driver monitoring and periodic responses. "Calculation of pass/fail scores was based on five performance index coefficients (linear combinations of the performance variables).

For each driver the five performance indices were calculated and compared to established performance criteria for each of the indices. The indices focused on the following five general categories: curvative error variability, divided attention response time variability, throttle activity variability, steering activity variability, longitudinal speed variability. A driver was required to obtain a passing score on each of the five performance indices to receive a passing score for the trial as a whole."

Relevant Findings:

- The drivers' typical workday length ranged from 6 to 15 hr with an average across all drivers of 11.89 h and a S.D. of 1.683.
- "The average number of days driving per week ranged from 3 (relief and part-time drivers) to 7, with an average of 5.35 days, standard deviation of 0.557 days."
- Drivers typically rated fatigue to be a problem for other drivers (21%) more often than for themselves (8%).
- A much lower proportion of drivers rated fatigue as "never" being a problem for them as did drivers in Hartley et al's study (13% as opposed to 35.5% in Hartley et al).
- 33% of drivers reported that they did not comply with the hours of service regulations (11 hours driving in one day) , and only 69% reported compliance with the requirement for minimum rest of 9 hours
- Drivers had an average of just one and a half meals per day (0.5 of a meal was defined as a light snack, usually while driving).
- The average Epworth Sleepiness Score of 7.53 (S.D. of 4.47) was substantially higher than the average score of 5.7 for truck drivers and 6.2 for automobile drivers reported in previous research (Maycock, 1995).
- 91% of all drivers passed all five of the performance criteria for the performance test on the simulator. "Of the 9% of drivers displaying driving performance below the criterion level, eight drivers failed the first performance criterion, a linear combination of measures predominantly associated with curvature error variability."
- "Of the drivers' activity and demographic measures, two were found to be particularly reliable predictors of simulator task performance: average distance driven per shift and driver age, $F(2, 98) = 8.42$, $P<0.01$. Drivers with an average daily route of fewer than 250 km and drivers 37 years and older were much more likely to fail the performance test." The authors noted that at this stage it was unclear "how to interpret the route length and age effects in the TOPS results"

(III)4.2 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." Department of Transportation, Federal Motor Carrier Safety Administration.

FMCSA Tech Brief, 2000/09 (FMCSA-MCRT-00-015)
"Effects of sleep schedules on commercial motor vehicle driver performance – Part 2"

Note: These studies were the primary source used to form a relationship between PVT and truck crash risk, and also contributed to the relationships embedded in the SAFTE/FAST sleep and performance model.

Description of Study

The studies were conducted to gather and analyze data on commercial motor vehicle driver rest and recovery cycles, effects of partial sleep deprivation, and prediction of subsequent performance. The project was composed of two studies

Field Study:

Study involved actigraphic assessment of sleep and driver/sleep logs, conducted with long and short haul CMV drivers over 20 consecutive days. The drivers wore the Walter Reed wrist actigraphs at all times except when bathing or showering. In addition they completed sleep logs on driver's daily log sheets to gather subjective information about sleep times, sleep latency, arousals during sleep, alertness upon awakening, naps (number and duration), and self-reported caffeine, alcohol and drug use. The data from each actigraph were downloaded to a personal computer, and each 24-hour actigraph recording period was examined for sleep in its entirety regardless of the duty status type or length indicated on the daily log sheet.

Laboratory Study:

Primary objectives of the laboratory study were to "1) determine the effects of four sleep/wake schedules on alertness and performance, and 2) develop an algorithmic model to predict performance on the basis of prior sleep parameters." Drivers had 3 days of orientation and baseline sleep in the laboratory before data collection commenced over 7 days of performance testing with 3, 5, 7, or 9 hours of sleep each night. The recovery period, that followed, lasted 4 days with 8 hours in bed each night. A wide variety of measures were utilized. Measures consisted of the psychomotor vigilance task (PVT), the cognitive performance assessment battery, driving simulator tasks (e.g., lane tracking) as well as sleep latency, EMG and sleepiness ratings. In addition to these measures, a number of health measures were taken (e.g., tympanic temperature, heart rate, and blood pressure). Primary objectives of the laboratory study were to 1) determine the effects of four sleep/wake schedules on alertness and performance, and 2) develop an algorithmic model to predict performance on the basis of prior sleep parameters." In addition to psychomotor vigilance

Principal Findings

Field Study:

- Both long- and short-haul drivers averaged approximately 7.5 hours of sleep per night, which is within normal limits for adults. "However, the short-haul drivers tended to consolidate their daily sleep into a single, off-duty period, whereas long-haul drivers obtained approximately half of their daily sleep total as daytime naps and/or during sleeper-berth time."
- As long-haul drivers obtained almost half of their daily sleep during work-shift hours (mainly sleep-berth time), it appears that they spend a significant portion of the work shift in a state

of partial sleep deprivation, until the opportunity to obtain on-duty recovery sleep presents itself.

- There was no off-duty duration that guaranteed adequate sleep for the long or short haul drivers. As drivers likely use a substantial portion of their off-duty time to attend to personal business, off-duty time must be of sufficient duration to allow drivers to accomplish these tasks and to obtain sufficient sleep. This may be particularly important for long-haul drivers, who often did not sleep at all during off-duty periods.
- The bulk of the first (main) daily sleep bouts for short-haul drivers were initiated between 2000 and 0200 hours. Sleep bouts initiated at these times lasted longer (i.e., clustered between 6 and 10 hours) than sleep bouts initiated at other times of day. Several of the sleep bouts initiated between these times lasted longer than 12 hours.
- Similar to the short-haul drivers, the majority of long-haul drivers' first sleep bouts were initiated between 2200 and 0359 hours. However, long-haul drivers initiated their first sleep bouts more frequently during 0000 and 0359 hours. The duration of long-haul drivers' first sleep bouts clustered between 6 and 10 hours in duration. Sleep bouts exceeding 10 hours in duration were uncommon and none exceeded 12 hours. Some sleep bouts were initiated in the early and late afternoon hours (1200 to 1959) and, unlike short-haul drivers, almost half of the first sleep bouts initiated during this time frame were longer than 4 hours in duration.
- There were large day-to-day variations in total sleep time for drivers in both groups. Sleep times varied for some long and short-haul individuals by up to 11.2 hours across the 20 study days for the long and short-haul drivers. Other drivers maintained more consistent sleep/wake schedules. Some individuals showed a pattern that suggested chronic sleep restriction with intermittent bouts of extended recovery sleep. The authors felt that this suggested that although work/rest schedules can be devised to help minimize CMV driver sleep debt, optimal enhancement of driver alertness and performance will require additional and imaginative approaches.

Lab Study:

- On average, subjects slept 2.9, 4.7, 6.3, and 7.9 hours for the 3, 5, 7, and 9-hour time in bed conditions respectively, and displayed dose-dependent performance impairment related to partial sleep loss. (As can be deduced from the above sleep times, as sleep restriction was more pronounced, sleep latency periods declined, resulting in greater sleep efficiency or proportionally more sleep in the available period.)
- Performance in the 3-hour sleep group typically declined below baseline within 2 to 3 days of sleep restriction.
- Performance in the 5-hour sleep group was consistently lower than performance in the 7- and 9-hour sleep groups.
- Performance in the 7- and 9-hour sleep groups was often indistinguishable and improved throughout the study. However, the authors did note that "even a relatively small reduction in average nighttime sleep duration (i.e., 6.3 hrs of sleep – the average amount of sleep obtained by the 7-hr group) resulted in measurably poorer performance – e.g., on the PVT. This decrement was maintained across the entire consecutive days of sleep restriction.
- Virtually no negative effects on performance were seen in the 9-hour sleep group.

- Sleep restriction effects were consistent. The degree to which "sleep restriction impaired performance was measure-specific". "Across tasks, speed and throughput were consistently affected". "In general, performance for the 3- and 5-hour sleep groups was below that of the 7- and 9-hour sleep groups." "Thus, restricting sleep resulted in dose-dependent performance impairment."
- All cognitive tasks were sensitive to differential sleep restriction.
- The PVT was the most sensitive measure. (It was also the performance measure which was the most resistant to changes in performance due to learning, an important issue when effects over many days are being examined.) Even the 7-hour group with 6.3 hours of sleep showed decreased performance using this measure across the 7 days.
- The majority of driving performance measures (e.g., increased lane-tracking variability increased driving speed, increased speed variability and increased running-off-road accidents) also showed dose-dependent and/or cumulative sleep restriction effects.
- Following chronic sleep restriction, the first 8 hours in bed (6.5 hours of sleep) was insufficient for restoration of performance on the PVT task.
- During the 4-day recovery phase (8 hours in bed each night), 5- and 7-hour sleep groups showed minimal or no recovery, remaining consistently below the 9-hour sleep group and below their own baseline levels for the PVT.
- The 3-hour sleep group showed some recovery for the PVT on the first day and more on subsequent days but also remained well below their own baseline and below the performance of the other groups.
- Subjects' recovery to baseline or near baseline levels of performance on the PVT often required a second or third night of recovery sleep.
- These data suggest that after sleep debt has occurred (3, 5, 7 hr time in bed) a single bout of 8 hours of night sleep leads to recovery but not full recovery. While further sleep is required for full recovery, the number of subsequent sleep periods to reach full recovery is unknown. For the 3 hour group, the data suggests that even 3 nights of normal sleep (8 hours spent in bed on each night) is not sufficient to restore performance to baseline levels (depending on the task). This suggests that full recovery from substantial sleep debt requires recovery sleep of extended duration (i.e., more than 8 hours of normal-duration sleep). This is a unique finding and requires replication.
- In contrast to the findings concerning PVT performance, the accident rate went back to baseline after one recovery day for all groups. In addition, lane position variability was near, but not quite back to baseline for all but the 9-hour group.
- On recovery days lane position variability was slightly worse for the 9-hour group who, after being allowed 9 hours in bed each night during the work period, were restricted to 8 hours of sleep.

- "The extant level of daytime alertness and performance capacity is a function not only of an individual's circadian rhythm, time since the last sleep period, and duration of the last sleep period, but is also a function of his/her sleep history, extending back for at least several days."

- Following more severe sleep restriction (e.g., the 3-hr group), recovery of performance was not complete after 3 consecutive nights of recovery sleep …this suggests that full recovery from substantial sleep debt requires recovery sleep of extended duration.

(III)4.3 Dingus, T., Neale, V., Garness, S., Hanowski, R., Keisler, A., Lee, S., Perez, M., Robinson, G., Belz, S., Casali, J., Pace-Schott, E., Stickgold, R., Hobson, J.A., The Impact of Sleeper Berth Usage on Driver Fatigue. FMCSA, FMCSA-RT-02-050, Washington, DC, November 2001.

Federal Motor Carrier Safety Administration. "Impact of sleeper berth usage on driver fatigue: Final Report." (2002). Report Number: FMCSA-RT-02-070

Klauer, S.G., Dingus, T.A., Neale, V.L. and Carroll, R.J. (2003) "The effects of fatigue on driver performance for single and team long-haul truck drivers." Driving Assessment 2003 – The Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design. Park City, Utah.

NB All quotes are from FMCSA summary.

Description of Studies

This report documents research that was conducted on sleeper berth usage. In addition to focus groups with long-haul operators a field study was conducted on sleeper berth usage for single and team drivers. The report outlines a number of factors, discovered in a series of 10 focus groups, which are important to successful sleeper berth usage for single and team drivers. Based on the results of the focus groups and an accompanying literature review, the researchers designed an on-road study with 56 drivers (47 male, 9 female; mean age=42.6 years) constituting 13 teams and 30 single drivers, to assess the effects of sleeper berth usage on sleep, driver error and critical incidents. In this study, long-haul truck drivers operated heavy trucks for a minimum of six continuous days, with the typical run being seven to 10 working days, on their regularly assigned route. Data collection systems were installed on the tractors used by the drivers to collect sleeper berth environmental data, driving performance information, video of the driver's face, and subjective alertness ratings and data from the Nightcap sleep system. Data (i.e., computer and video) were collected prior to and during critical incidents such as lane and steering deviations.

Relevant Findings

Focus Groups

- "Team versus single driving was identified as a very important factor for drivers relating to quality of sleep." Drivers either loved or hated team driving and discussed various issues relevant to their preference (e.g., trust, partner's driving ability, driving smoothly, etc.). Drivers also discussed various equipment issues with respect to comfortable sleeping arrangements (e.g., noise, air-ride vs. spring-ride trucks, etc.,)

Field Study: Team Driving vs. Single Driving

- Single drivers were involved in significantly more critical incidents than team drivers. They were involved in "four times the instances of "very/extremely drowsy" observer ratings than were team drivers, and were more likely to push themselves to drive on occasions when they were very tired."
- More than one-half of the most severe of the critical incidents were caused by four of the thirty single drivers. In contrast, team drivers were generally very successful at avoiding circumstances of extreme drowsiness, drove much less aggressively and made fewer errors than single drivers.
- The main effect for segment of day was significant ($p < 0.05$). Team drivers tended to exhibit critical incidents associated with extreme fatigue during the (morning and night hours (morning: 04:00 to 11:59; afternoon: 12:00 to 17:59, night: 22:00 to 03.59). Single drivers "tended to show fewer extreme fatigue-related critical incidents during the morning hours, with gradually more critical incidents being attributed to the very drowsy categories during the evening and nighttime hours". The authors note that single drivers "were exhibiting signs of extreme fatigue during all hours of the day while team drivers only showed signs of fatigue during the nighttime and morning hours."
- Overall, team drivers were able to better manage their fatigue and critical incident involvement than were single drivers. This may be because team drivers are more likely to effectively trade-off driving duties with their partner prior to becoming extremely fatigued. It is also possible that, in effect, drivers undergo a natural "screening" process. Focus group participants noted that team drivers must be trustworthy with regard to their driving ability and be considerate of their resting partner.

Field Study: Quality of Sleep

- A number of findings indicated that the quality and depth of sleep was worse (e.g., more sleep disturbances) on the road, particularly for team drivers. They found that while the vehicle was in motion, the noise and motion environment in the sleeper berth degraded the drivers' sleep.

Field Study: Hours of Service

- Based on a report by Wylie et al., (1996), there were relatively few instances (about 2.2 percent) of "extreme drowsiness," with most of these instances being experienced by single drivers, again with a high rate of the occurrence of this level of fatigue on the second or third shift after the first day of a multi-day drive."
- The authors note that it "appears that the combination of long driving times and multiple days provides the greatest concern, with several results pointing to the presence of cumulative fatigue." As a result they believe that the length of shifts in the later stages of a trip must also be considered. However, the authors point out that "critical incidents and/or driver errors did not increase directly with the hours beyond the regulation," and that "there was a substantial decrease in the rate of critical incidents during some of the more extreme violations." However, they do caution that this should not be interpreted to mean that hours of service should be expanded due to the following two reasons: "First, it may be possible that the drivers were making a point to driver more carefully and

cautiously because they were operating outside of the regulation and did not want to get stopped by law enforcement officials. Alternatively, they may have only risked driving outside of the regulations because they felt alert and knew that they could continue to drive safely."

(III)4.4 Gillberg, M., Kecklund, G., and Akerstedt, T. (1996). "Sleepiness and performance of professional drivers in a truck simulator – comparisons between day and night driving." Journal of Sleep Research, 5, 12-15.

This paper summarizes a study comparing daytime and night-time performance of professional drivers on a simulated driving task. The authors noted that to their knowledge no studies had been conducted reporting on the effects of sleepiness on night driving performance in a dynamic truck simulator using professional drivers as subjects. The secondary purpose of the study was to test whether a nap, or a rest pause, would affect performance.

Nine professional drivers participated 4 times in a counterbalanced repeated measures design. "The conditions were day driving (DAYDRIVE), night driving (NIGHTDRIVE), night driving with a 30 minute rest (NIGHTREST), and night driving with a 30 minute nap (NIGHTNAP)." Time of day was not specified. "Each condition consisted of three consecutive 30-min periods." The 30-min duration of each period was an adaptation to the maximal continuous driving period allowed by the simulator software. "For the DAYDRIVE and NIGHTDRIVE all periods were spent driving while the second period was either a rest pause or a nap for the other two conditions." "Mean speed, standard deviation of speed and, standard deviation for lane position were recorded. Self ratings of sleepiness (e.g., Karolinska Sleepiness Scale) were obtained before and after each 30-min period. Reaction time tests and 10 minute standardized EEG/EOG recordings were obtained before and after each condition". EEG/EOG recordings were obtained before and after each condition. EEG/EOG were also recorded continuously during driving.

Relevant Findings

- The authors noted that despite the relatively short task (continuously driving for only 30 minutes at a time) statistically significant differences between day and night driving performance could be demonstrated. The effects on driving were small but significant: night driving was slower, with a higher variability of speed, and higher variability of lane position.
- Subjective and EEG/EOG sleepiness were clearly higher during the night conditions.
- Reaction time performance was not significantly affected by conditions.
- The authors noted that the task per se affected alertness, as indicated by the clear increase in subjective and electrophysiological sleepiness as well as in reaction times over the three periods even for the day driving condition.
- Neither the nap nor the rest pause had any effect. The authors note that a nap of the same duration during the day, on the other hand, has been shown to have clear positive effects. They felt that as sleep inertia tends to be more pronounced with the longer wake times that will precede night naps (Dinges, 1985), this might have obscured the possible positive effects of the nap in the present experiment. It is clear, however, that the nap did not have a negative effect which could have been the result if severe sleep inertia had

occurred. The authors conclude that the most reasonable explanation to the lack of nap effect is that it was too short to counteract the low levels of alertness during the circadian trough after an extended time awake.

(III)4.5 Hanowski, R. J., Wierwille, W. W., Gellatly, A. W., Early, N., and Dingus, T. A. (2000). "Impact of local short haul operations on driver fatigue." Department of Transportation Federal Motor Carrier Safety Administration.

Description of Study

This paper summarizes the results of an on-road field study focusing on the fatigue experienced by local/short haul truck (L/SH) drivers (i.e., trips less than 100 miles from home base) on typical workdays, whose vehicles were instrumented with data collection equipment. Forty-two male L/SH drivers (mean age = 31) participated in the study. Drivers completed 2 weeks of Monday-Friday daytime driving on normal delivery routes that were within 100 miles of home. Their distribution of work consisted of driving (28%), loading/unloading (35%), other assignments (26%), waiting to unload (7%), eating (2%), resting (0.5%) and other activities (1.5%).

The authors used subjective, objective and physiological measures to assess fatigue, inattention and drowsiness. Subjective measures included self-report on levels of stress. Objective measures included the degree of eyelid closure. Physiological measures included indications of sleep quantity and quality as collected by wrist activity monitors. In addition the “black box” data collection equipment installed in the truck collected driver performance associated with “critical incidents” (i.e., near-crash events). Several small video cameras were used to monitor each truck driver and surrounding traffic situation, and sensors collected date from the vehicle’s instruments. The authors conducted analyses of videotape of the three-minute interval preceding the start of a critical incident. An incident was defined as a control movement exceeding a threshold based on driver or analyst input. Analysts recorded eye transitions and the proportion of time that the driver’s eyes were closed/nearly closed, or off the road, during these three-minute intervals.

Relevant Findings

- Over the two-week period, there were 77 incidents (average 1.8 per driver) where the driver was judged to be at fault. Inattention was thought to be involved in 57 critical incidents, and fatigue a contributor to 28 critical incidents (i.e., 20.8% of incidents where the L/SH driver was judged to be at fault).
- The majority of the L/SH driver at fault critical incidents were caused by about one-quarter of the drivers: ten of the 42 drivers were involved in 86% of the incidents.
- The younger and less experienced drivers were significantly more likely to be involved in critical incidents and exhibited higher on the job drowsiness.
- “Drivers tended to be involved in fatigue-related incidents earlier in the workweek. There were no fatigue-related critical incidents after the fourth day of the workweek.”
- The highest frequency of driver-at-fault incidents was between noon and 1 PM. The increase in incidents during these periods may be attributed to increased exposure.

- Drivers demonstrated, to a statistically significant level, signs of fatigue for a time period immediately preceding incident involvement where the L/SH driver was judged to be at fault.
- During the study, the drivers' mean sleep was 6.43 hours per night (sleep log) and 5.31 hours based on the Actiwatch (developed by Mini Mitter Co., Inc.).
- Data was divided into two groups where fatigue was apparent or not apparent. "To classify incidents into one of these two groups, threshold values for PERCLOS and OBSERV were set such that fatigued drivers were defined as having PERCLOS greater than or equal to 0/08, or an OBSERV value greater than or equal to 40. If an event did not meet one of these criteria, then the driver was deemed to be 'not fatigued.'" Drivers who showed evidence of fatigue and were involved in fatigue-related incidents had less sleep and of a poorer quality than drivers who did not show signs of fatigue. The drivers from the beverage company typically worked 10 to 11 hours per workday. The snack food drivers worked roughly 12 hours per workday. The majority of drivers worked five days per week.
- The self-reported amount of sleep and quality of sleep for the night before the incident were less when the driver was categorized as being fatigued. Drivers in the fatigue group had 5.33 hours of sleep compared to 6.13 hours in the non-fatigue group.
- "…much of the fatigue that the drivers' experienced was brought with them to the job, rather than being caused by the job." The authors concluded that off-duty behavior was the "primary contributing factor in the level of fatigue that was demonstrated during the workday."
- Drivers in the fatigue group spent more hours driving during the day of the critical incident as compared to drivers in the no-fatigue group.

(III)4.6 O'Neill, T.R., Kruegar, G.P., Van Hemel, S.B., and McGowan, A.L. (1999). "Effects of operating practices on commercial driver alertness." Rep. No. FHWA-MC-99-140, Office of Motor Carrier and Highway Safety, Federal Highway Administration, Washington, D.C.

O'Neill, T.R., Krueger, G.P., Van Hemel, S.B., McGowan, A.L. and Rogers, W.C. (1999) "Effects of cargo loading and unloading on truck driver alertness." Transportation Research Record, 1686, pp. 42-48.

Rogers, W. (2000) "Effects of operating practices on commercial driver alertness." Proceeding of the Conference Traffic Safety on Two Continents held in Malmo, Sweden, September 20 – 22, 1999.

Tech Brief (1999) (FHWA-MCRT-99-008) "Effects of operating practices on commercial driver alertness."

Description of Study

This project consisted of focus groups, a driver survey and interviews with CMV drivers focused on the physical requirements (loading/unloading) across the industry. This was followed by a driving simulator study which investigated "fatigue-related related decline in driving performance resulting from loading and unloading cargo," "non-duty time (rest and recovery) required to reestablish baseline fitness for duty," and "driver performance under a sustained 14 hours on/10 hours off schedule. Researchers examined driver performance over a 15-day period." Ten male CMV drivers operated a "driving simulator in simulated long-haul runs for a period of 15 days, including occasional loading/unloading sessions and a relatively high frequency of simulated crash-likely events." Performance measures and measures of subjective drowsiness were collected. In addition, participants wore wrist activity monitors to assess the amount of sleep.

Drivers were held to a schedule of 14 hours on duty (12 hours driving plus scheduled breaks) followed by 10 hours off duty. The daily driving schedule ran from simulator engine start at 0700 to shutdown at 2100. Breaks were taken on the experimental schedule and not at the subject's discretion (30-minute break at 1000, a 45-minute lunch break at 1345, and a 30-minute break at 1730). During week one of driving, half of the drivers conducted simulated loading/unloading operations for three days and no loading/unloading operations in week 2. The remaining drivers did the reverse (i.e., loaded in week 2). On loading days, drivers performed two 90 minute loading/unloading sessions during the driving day, one in the morning, and one in the afternoon.

During driving days a Psychomotor Vigilance Task (PVT) was administered 3 times (0645, 1330, 2100). Subjective examination of video records of drivers during simulated operations were conducted for samples taken from periods during which parallel indicators showed evidence of good or poor performance. Multiple measures were employed to gauge recovery, including sleep patterns, sleep latency, subjective sleepiness, and the Psychomotor Vigilance Test (PVT). These measures were repeated regularly 4 times each day (0900, 1300, 1700, 2100) during the 58-hour rest and recovery period.

The effects of loading and unloading task were mixed. There was an initial improvement in alertness; however, this effect wore off as the day progressed and may have contributed to a decrease in overall performance after 12 to 14 h of duty." "Drivers recovered baseline performance within 24-hours of the end of a driving week and should be fit to resume duty after 36 hours." "A schedule of 14 hours on duty/10 hours off duty for a 5-day week did not appear to produce cumulative fatigue."

Relevant Findings

- There was a gradual decline in driver response quality over time (hours at the wheel). There were slight performance degradations in the mid-afternoon, but there were improvements after each break, whether for rest, meals, or loading activities. The authors did not discuss how long the improvement effect lasted.
- The rest breaks had an influence on critical safety measures. For example, the effects of 6.5 hours of driving were reduced to starting levels by the one hour lunch break for non-loading days. While the recovery effect of a rest break is not surprising, the magnitude of the effect is striking. (Note: As the loading/unloading variable contributed to a significant interaction it is of use to examine the days when no such activity occurred, since these are more typical of the industry as a whole, and are free of the loading/unloading variance).

- After the morning physical activity, there was an improvement in driver response to crash-likely simulated situations, probably due to a short-term invigorating effect associated with physical exercise and a break in driving routine.
- The afternoon loading/unloading session did not have the same effect on drivers. Driving performance deteriorated more rapidly after the afternoon physical activity, suggesting that cumulative physical/general fatigue and time-of-day effects are sufficient to overpower some short-term effects of a change in activity. Driving performance did return to starting levels near the end of the day.
- The ability to maintain speed within posted limits and gear shifting performance both deteriorated somewhat during the latter part of the driving day. The simultaneous occurrence of the two suggests deterioration in physical coordination and vigilance late in the day, but there was no consistent linear relation to hours of driving.
- The authors note that there is “no useful way to compare the cumulative effects of the 14/10 schedule with other possible schedules (including those logically subsumed, such as 10-hour and 12-hour duty periods) because the cumulative effects for each are confounded.” However, what can be said about cumulative effects is that they “appear to be nil for practical measures (e.g., probe scores) and mild for parallel subjective measures such as subjective sleepiness.” Duty-day subjective sleepiness, reaction time response, and measures of driving performance showed a slight but statistically significant deterioration over the driving week, but driver response in crash-likely situations did not show cumulative deterioration. The schedule of 14 hours on duty/10 hours off duty (12 hours driving) for a 5-day week did not appear to produce significant cumulative fatigue over the 2-week testing period.
- While there was an increase in measured sleep and a decrease in sleep latency on the first off-duty rest day following the end of the driving week, the authors do not believe that the peak sleep periods during the “weekend” days were due principally to sleep deprivation. They noted that drivers varied in the number of hours of sleep per night, and a case-by-case examination of driver sleep patterns did not show a higher rebound for those who slept less during the driving week, indicating that the variation observed did not represent deprivation. They felt that the drivers did not appear to have accumulated significant sleep loss.
- Sleep latency was measured between 2200 and 2230 on the last driving day (Friday) of each week. At this point drivers were not ready to sleep, however tired they might feel, since they had just been released from a 14-hour driving day. The second sleep latency measurement was taken between 0900 and 0930 the next morning (Saturday), shortly after the drivers had awakened from a night’s sleep. The third sleep latency measurement was taken at 1300 on Saturday and proved to be dramatically the shortest sleep latency.
- Drivers returned to baseline reaction time performance and alertness within 24 hours after the end of a driving week, as shown by sleep latency, reaction time testing, and driver rating of subjective sleepiness. This effect was generally consistent across drivers. The typical recovery pattern involved extra sleep during the first rest day verified by wrist activity monitor, and an increased level of sleepiness during the afternoon of the first day (indicated by shorter sleep latency)

(III)4.7 Williamson, A., Feyer, A.M., Friswell, R., and Finlay-Brown, S. (2000) "Demonstration project for fatigue management programs in the road transport industry: Summary of findings."

Description of Study

The aim of this project was to evaluate work-rest schedules to begin to identify some model work-rest schedules to provide companies and drivers flexibility in meeting their operational needs and to manage fatigue most effectively. The paper is a summary of findings of the results of three different reports. As this paper a summary of findings, the paper does not include a great deal of detail. The first report describes the identification of three performance measures that have demonstrated sensitivity for detecting fatigue and its effects so that they can be used in developing models of work-rest schedules. The second and third reports focus on on-road and simulated evaluations of current and alternative work-rest schedules.

The first step in this project involved a comparison of performance on a "range of performance tests under conditions in which study participants should be tired, with performance under conditions in which they had been exposed to varying doses of alcohol" to identify measures that have demonstrated sensitivity for detecting fatigue. Performance tests were administered at regular intervals over time with increasing sleep deprivation (i.e., participants were kept awake a total of 28 hrs) and increasing blood alcohol levels (BAC) (four doses of alcohol to achieve increasing BAC). The authors could then identify which tests were sensitive to increasing alcohol doses and those which were sensitive to increasing sleep deprivation.

The second and third reports focused on four evaluations, consisting of two evaluations of the current working hours regulations in New Zealand, and two evaluations of alternative approaches to work-rest schedules. All the evaluations except one (a simulation) were conducted on-road using the performance measures developed in the first step of this project. Participants started the study after being on break for 24 hours to "obtain baseline information about performance when rested". Ratings of fatigue and performance were then taken at "strategic points across the work-rest schedule between two long 24 hour breaks." The alternative approaches to work-rest schedules were evaluated in a simulation study and an on-road study. The simulation study looked at the extension of the daily working hours limit from a "maximum of 14 hours in a 24 hour period to up to 16 hours in a 24 hour period. The overall schedule covered 60 hours. The longer hours were balanced by beginning and ending the schedule with a 6 hour break and having a mandatory 6 hour break at some point in the intervening 48 hours. Short breaks of at least 15 minutes were also required after every 3 hours of work. The evaluation was conducted as a simulation because it had not yet been authorized to be trialed on the road as part of the pilot FMP."

In contrast, the second evaluation of an alternative approach to work-rest schedules could be conducted on the road because "it was in operation as part of the pilot FMP." It "differed from the regulated hours regime by allowing for longer sustained periods of work at a stretch and splitting of the mandatory breaks between them. The regulated hours allow only five continuous hours of work before drivers take a break of at least 30 minutes. In this alternative schedule, drivers could work up to six continuous hours and only needed to take breaks in 15 minute periods, although they needed to take 30 minutes in total in every six hour period. The FMP also allowed drivers to divide the mandatory six hour continuous break into shorter sections. In all other ways, the work-rest schedule was the same as the regulated regime."

Relevant Findings

- While most of the tests showed deterioration in performance with increasing alcohol doses, not all the tests did so for increasing sleep deprivation.
- 0.05% BAC equivalence occurred at between 17 and 19 hours of sleep deprivation for most tests. This means that after around 17 hours of wakefulness, performance capacity was sufficiently impaired to be of concern for safety."
- There was little evidence that current working hours led to performance decreases large enough to "constitute a significant safety risk compared to alcohol equivalent levels at 0.05% BAC."
- In the simulation study of an alternative compliance approach, drivers were able to manage fatigue effectively over the first 16 hours of the schedule, however, their performance deteriorated significantly by the middle of the second 16 hour period. Performance at this time was "considerably poorer than the 0.05% BAC alcohol equivalence standard. It seems that the 6 hour break was insufficient to allow recovery and recuperation from the demands of the previous long day …" The work-rest schedule was "too demanding for drivers to manage fatigue effectively."
- The results of the road test evaluation of the second alternative compliance approach showed that "reaction speed showed a deterioration across the study to levels that were suggestive of an increased safety risk based on the 0.05% BAC equivalent standard for performance".

- Both evaluations showed, however, that performance capacity deteriorates and fatigue levels increase in relation to factors like increasing hours of work (especially night hours), short breaks and breaks that only allow short or poor quantity sleep). While fatigue and performance capacity seems to be maintained with safe limits under the regulated regime, these findings indicate that where drivers or companies take the work-rest schedules beyond the current limits, they are likely to be increasing the risk of performance decrements sufficient to compromise safety.

- Evaluation of the current working hours regime suggests that provided drivers are rested to begin with, one full cycle of the regulated regime does not produce fatigue or performance capacity decrements that of concern for safety. There is considerable evidence however that performance decrements increase significantly as the schedule becomes more demanding. This is a warning signal for the development of alternative approaches to ensure that schedules are designed that do not simply increase the demands on drivers. The evidence from both evaluations of alternative compliance schedules suggested that they increased the demands on drivers, but did not balance them sufficiently with rest in order to allow recuperation and recovery from accumulated fatigue."

- These results do not mean that the working hours regulatory regime is the only satisfactory approach to managing fatigue. The results show clearly that it is possible to increase trip length to 16 hours, say, and still maintain good performance levels. It is not possible, however, to continue to do 16 hour trips without a longer break than is usually allowed, even in the regulated regime."

(III)4.8 ***Wylie, C.D. "Driver drowsiness, length of prior principal sleep periods, and naps." (1998). Transportation Development Centre. Report No. TP 13237E***

Wylie, C.D., Shultz, T., Miller, J.C., and Mitler, M.M. (1997) "Commercial motor vehicle driver rest periods and recovery of performance."

Wylie, C.D., Shultz, T., Miller, J.C., Mitler, M.M., and Mackie, R.R. (1996) Commercial motor vehicle driver fatigue and alertness study." (Executive Summary & Technical Summary)

Mitler, M.M., Miller, J.C., Lipsitz, J.J., Walsh, J.K., and Wylie, C.D. (1997). "The sleep of long-haul truck drivers." New England Journal of Medicine, 337(11).

Freund, D. and Vespa, S. (1997) "U.S./Canada study of commercial motor vehicle driver fatigue and alertness". Proceedings of the XIIIth World Meeting of the International Road Federation, Toronto, Ontario. June 16 – 20, 1997.

Description of Study

This paper summarizes the results of an on-road study with 80 drivers in the U.S. and Canada. The goal of this study was to assess fatigue related to Canadian vs. U.S. driving schedules. Data (e.g., loss of alertness, performance, etc.) was collected on drivers for over a period of 16 weeks. Drivers drove one of four driving schedules. Time of day was the "strongest and most consistent factor influencing driver fatigue and alertness." In contrast "hours of driving (time-on-task) was not as strong or consistent predictor of observed fatigue." "There was some evidence of cumulative fatigue across days of driving."

The study used a between-subjects design involving four driving schedule conditions: C1- 10 hr daytime (5 consecutive days); C2-10 hr rotating (5 consecutive days, starting 3 hrs earlier each day); C3- 13-hr nighttime start (4 consecutive days); C4- 13-hr daytime start (4 consecutive days). The study design "was developed to comply with existing U.S. and Canadian hours-of-service regulations." "The four schedules provided different amounts of time off between trips. Condition 1 provided about 11 hours off, while the other three conditions provided about 8 hours off." Various measures were taken: driving task performance (e.g., lane tracking, steering wheel movement), driving speed and distance monitoring, performance on surrogate tests (i.e., code substitution, critical tracking test, simple response vigilance test), continuous video monitoring, physiological measures as well as driver-supplied information (e.g., daily logs, Stanford Sleepiness Scale rating).

Relevant Findings

- Time of day was far more important than time-on-task or cumulative number of trips in predicting driver fatigue.

- Drivers in the C3-Nighttime condition had the least amount of sleep of all the conditions.
- Night driving (e.g., from midnight to dawn) was associated with worse performance on four important criteria" (e.g., average lane tracking standard deviation, etc.).
- "There was some evidence of cumulative fatigue across days of driving. For example, performance on the Simple Response Vigilance Test declined during the last days of all four conditions."
- Drivers had approximately 2.5 hours of sleep than the amount of sleep they identified as their ideal.
- Drowsiness in Conditions C3Nighttime and C4Daystart was markedly greater during night driving.
- The observed prevalence of drowsiness formed a distinct peak about 8 hours wide, spanning late evening until dawn, and a 16-hour trough.
- There was probably greater drowsiness in Condition C2-10 rotating, trips 4 and 5, because the rotating schedule had caused these last trips, on average, to be driven through the night. Although disruption of circadian rhythms and cumulative fatigue probably contributed, time of day appeared to be a major factor.

(III).5 TRUCK CRASH RISKS AND COSTS

(III)5.1 ICF Consulting and Imperial College Centre for Transportation Studies "Cost-Benefit Analysis of Road Safety Improvements" Final Report submitted to the European Commission, Brussels, Belgium, June 2003

Description of Study

The European Commission (EC) was in the process of revising a number of road safety regulations primarily associated with the harmonization and enforcement of these laws through the 15 members European Union at the time. The cost-benefit study was performed to support this initiative by evaluating the benefits and corresponding costs of applying international best practices in enforcing laws relating to speeding, drunk driving seat belt use, and selected commercial vehicle safety regulations. The section of the study addressing the reformulation and enforcement of commercial vehicle hours of service and vehicle condition laws considered many of the same issues as those raised in the RIA analysis for FMCSA. Because the study relied mainly on European and other international sources, the information developed was largely independent of the sources used for this RIA analysis, and could provide another perspective on some key issues.

Relevant Findings:

- The fraction of truck involved fatal crashes where the truck driver was at fault in multi-vehicle was estimated at 17% by one source and 16% by another source, which also estimated that there was shared responsibility in another 14% of multi-vehicle crashes. In addition, the truck driver is at fault in the 20% of crashed that only involve a single vehicle. Taken together these results suggest the truck driver is at fault in about 36% of all truck-involved fatal crashes. In addition, one source suggested that the truck driver was at fault in a higher fraction of non-fatal crashes, up to 50%, but the data are probably less reliable.

- Of the crashes where the truck driver was at fault, the sources suggested that fatigue was a significant factor in 15-20% of all crashes, and up to 30% in fatal crashes. This leads to an estimate that fatigue is a significant factor in between 6 and 10% of all truck-involved crashes. Several sources make the observation that truck driver lifestyle off the job is a significant factor in fatigue-related crashes, and cannot be easily controlled by regulations or trucking firm managements.
- Several sources used showed that better safety management by trucking firms could have a substantial impact on crash rates, especially by raising the performance of the worst performing firms and drivers. The improvements extended beyond just HOS related crashes and could involve defensive driving techniques, better vehicle condition, better scheduling and improved pay and working conditions. Substantial reductions in crash risk, in the range 20 – 30% were cited is some example of applying such practices.
- Average per-crash costs for fatal and injury crashes were estimated at approximately 77,000 Euros, equivalent to $US 93,000. Given relatively higher medical and fatality costs applicable in the US, the corresponding cost under US conditions would be 50-100% higher.

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APPENDIX (IV) SUPPLEMENTAL BIBLIOGRAPHY

1. Arnold, P.K., Hartley, L.R., Hochstadt, D., and Penna, F. “Hours of work, and perceptions of fatigue among truck drivers.” (1997). *Accident Analysis & Prevention*, 29 (4) 471-77.

2. Baas, P.H. (Transport Engineering Research New Zealand (TERNZ)), Charlton, S., and Bastin, G. (2000) “Survey of New Zealand truck driver fatigue and fitness for duty.” 4th International Conference on Fatigue and Transportation, Fremantle, Western Australia.

3. Balkin, T, Thome, D., Sing, H., Thomas, M., Redmond, D., Wesenstein, N., Williams, J., Hall, S., and Belenky, G. “Effects of sleep Schedules on Commercial Motor Vehicle Driver Performance” FMCSA Report 2004.

4. Dingus T., Neale, V., Garness, S., Hanowski., R., Keisler, A., Lee, S., Perez, M. and Robinson, J. A. “Impact of Sleeper Berth Usage on Driver Fatigue” Final Report, FCMSA-RT-02-070, 2002.

5. Ken Campbell “Estimates of the Prevalence and Risk of Fatigue in Fatal Crashes Involving Medium/Heavy Trucks Update for 1991-2002 TIFA Files.” Letter Report to FMCSA, February 25, 2005

6. Ken Campbell “Comparing GES and LTCCS Preliminary (December 22) LTCCS File” Letter Report to FMCSA, March 11, 2005.

7. Feyer, A.M., Williamson, A., Friswell, R. “Balancing work and rest to combat driver fatigue: An investigation of two-up driving in Australia.” (1997). *Accident Analysis & Prevention*, 29 (4) 541-53.

8. Freund, D. and Vespa, S. (1997) “U.S./Canada study of commercial motor vehicle driver fatigue and alertness”. Proceedings of the XIIIth World Meeting of the International Road Federation, Toronto, Ontario. June 16 – 20, 1997.

9. Gillberg, M., Kecklund, G., and Akerstedt, T. (1996). “Sleepiness and performance of professional drivers in a truck simulator – comparisons between day and night driving.” *Journal of Sleep Research*, 5, 12-15.

10. Hakkanen, H. and Summala, H. (2000). “Driver sleepiness-related problems, health status, and prolonged driving among professional heavy-vehicle drivers.” *Transportation Human Factors*, 2(2), 151-171.

11. Steven R Hursh, Daniel P. Redmond, Michael L. Johnson, David R. Thorne, Gregory Belenky, Thopmas L. Balkin, William F. Storm, James C. Miller and Douglas R. Eddy “Fatigue Models for Applied Research in Warfighting”, Aviation Space and Environmental Medicine, Vol 75, Number 3 Supplement, 2004.

12. ICF Consulting and Imperial College Centre for Transportation Studies “Cost-Benefit Analysis of Road Safety Improvements” Final Report submitted to the European Commission, Brussels, Belgium, June 2003

13. Paul P. Jovanis, Sang-Woo Park, Ko-Yu Chen, "Crash Risk and Hours Driving: Interim Report" Letter report to FMCSA, Pennsylvania Transportation Institute, Penn State University, February 25, 2005

14. Paul P. Jovanis, Sang-Woo Park, Ko-Yu Chen, "Crash Risk and Hours Driving: Interim Report II" Letter report to FMCSA, Pennsylvania Transportation Institute, Penn State University, April 15, 2005

15. Klauer, S.G., Dingus, T.A., Neale, V.L. and Carroll, R.J. (2003) "The effects of fatigue on driver performance for single and team long-haul truck drivers." Driving Assessment 2003 – The Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design. Park City, Utah.

16. Mitler, M.M., Miller, J.C., Lipsitz, J.J., Walsh, J.K., and Wylie, C.D. (1997). "The sleep of long-haul truck drivers." *New England Journal of Medicine*, 337(11).

17. Morrow, P. C., and Crum, M. R. "Antecedents of Fatigue, Close Calls and Crashes Among Commercial Motor Vehicle Drivers" Journal of Safety Research, Vol 35, Number 1, 2004.

18. Reebie Associates (2002). "Day-of-Week Motor Carrier Demand Patterns," June, 2002.

19. Rogers, W. (2000) "Effects of operating practices on commercial driver alertness." Proceeding of the Conference Traffic Safety on Two Continents held in Malmo, Sweden, September 20 – 22, 1999.

20. Williamson, A., Feyer, A.M., Friswell, R., and Finlay-Brown, S. (2000) "Demonstration project for fatigue management programs in the road transport industry: Summary of findings."

21. Wylie, C.D. "Driver drowsiness, length of prior principal sleep periods, and naps." (1998). Transportation Development Centre. Report No. TP 13237E

22. Wylie, C.D., Shultz, T., Miller, J.C., and Mitler, M.M. (1997) "Commercial motor vehicle driver rest periods and recovery of performance."

APPENDIX (V) REVISIONS TO THE TOT FATIGUE CRASH ANALYSIS

This appendix reviews how the effects of extended driving hours (i.e., time on task or TOT) were taken into account in the cost benefit modeling, and then responds to questions about the analysis raised in the appeals court. As shown below, careful consideration of the analysis uncovered several necessary revisions, but the net effects of these revisions are minor.

(V).1 Original Analysis

The goal of the analysis was to find the change in fatigue-related crash risks that would result from eliminating driving in the 11th hour. Assuming motor carriers will still deliver the same volume of freight even without the 11th hour, we can presume that driving not done in the 11th hour will be done by additional drivers, in somewhat shorter trips. There will still be crashes in those shorter trips; indeed, there will still be fatigue-related crashes in those shorter trips. What must be calculated, then, is the average fatigue-related crash rate in trips that allow the 11th hour compared to the rate in the replacement trips that do not.

The analytical approach to adding an explicit TOT effect to the fatigue model was to determine a functional relationship between TOT and the measured percentage of crashes attributable to fatigue, relative to typical fatigue levels, and to use that relative risk to scale up the overall fatigue crash risk for driving hours with above-average fatigue percentages. All estimated fatigue crash risks were then scaled in such a way as to yield an average fatigue crash risk of seven percent under baseline conditions, which is the rate projected for long-haul driving in earlier modeling.

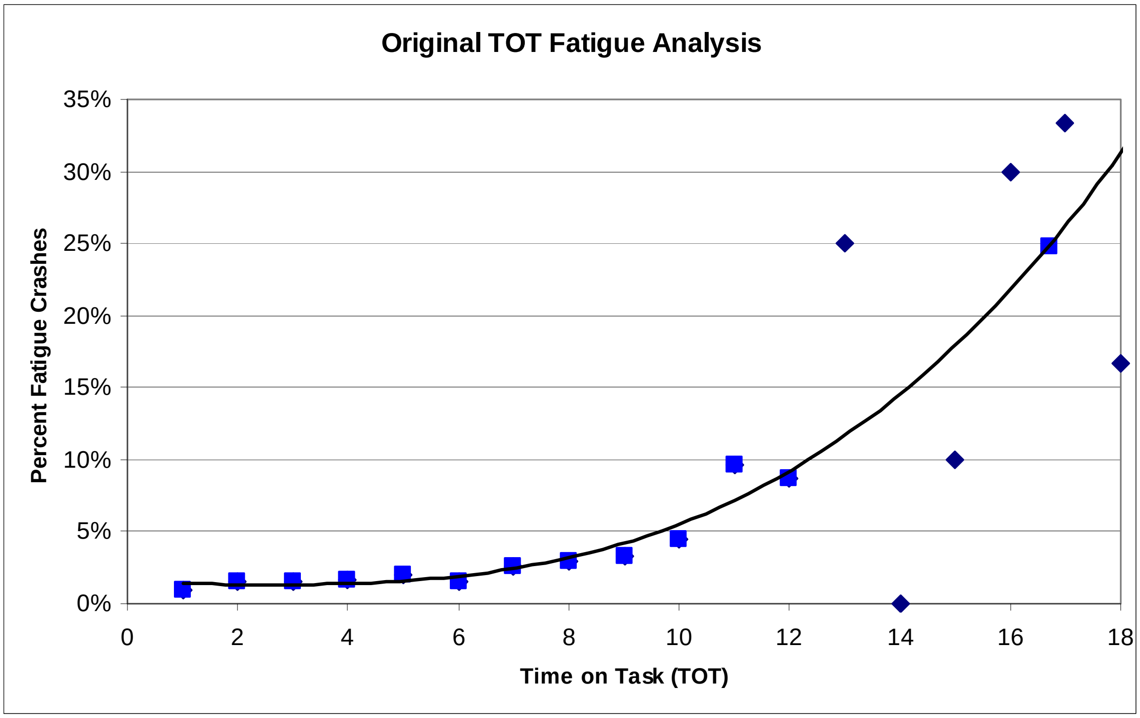
To derive a functional relationship between TOT and the percentage of crashes caused by fatigue, FMCSA used TIFA data from 1991 through 2002. For each TOT level from the first hour through the 12th, the average percentage of crashes caused by fatigue was computed. Extremely few data points were available for TOT levels beyond 12. To make it possible to use the limited data without introducing unreasonable variability for the estimated fatigue percentage at high TOT levels, the TOT and fatigue percentages for the crashes beyond 12 hours were averaged over all the crashes: the average percentage of fatigue-related crashes for these 101 crashes was 24.75%, and the average TOT was 16.73 hours.

The original cubic modeling approach fitted a cubic regression of the form

Prob(Crash is fatigue-related | crash occurred at hour h of driving)
$= a0 + a1 \times h + a2 \times h^2 + a3 \times h^3 + \text{error}.$

This model was fitted to the observed proportions of fatigue-related crashes using multiple linear regression. For these analyses, instead of using individual data points for h greater than or equal to 13, the overall proportion of fatigue-related crashes for all hours greater than equal to 13 was calculated and assumed to occur at hour 16.73, the average of the times of task for all the crashes with h greater than or equal to 13.

Exhibit (V)-1 Original TOT Fatigue Analysis



Using the cubic function, FMCSA calculated the probability that a crash at a given TOT would be coded as fatigue-related. In the modeling, each fatigue probability for TOT levels of 8 or more has been divided by a measure of the average fatigue related probability across the first 11 hours, as seen in the TIFA data. For TOT less than 8, no incremental fatigue risk was calculated on the grounds that for these hours fatigue was at or below average. As discussed further below, the lack of adjustment for the hours before 8 biased the results, and needs to be addressed in revising the analysis.

This approach created fatigue adjustment factors. For each hour of driving that was modeled, the predicted fatigue crash levels in the absence of a TOT effect were multiplied by these factors At the end of the analysis, all of the predicted fatigue percentages were scaled up so that the expected fatigue-related crashes in the baseline equaled 7%, which was the predicted fatigue-related percentage for LH operations in the 2003 analysis.

As intended, this analysis would calculate the reduction in crash risks resulting from banning the 11th hour: in a model run that allowed the 11th hour, a fair number of the hours of driving would fall into hours 10.5 to 11; their predicted "raw" non-TOT-adjusted fatigue crash likelihoods would be multiplied by a factor greater than 1.0, inflating the raw values to reflect the higher fatigue levels expected at high TOT levels. In runs that eliminated the 11th hour, the predicted non-TOT fatigue crash risks would be multiplied by generally smaller TOT multipliers, and so the predicted average crash risk would be lower than in the run that allowed the 11th hour. Using this method, and scaling both runs up by multiplying the TOT-adjusted values so that the baseline run showed 7 percent fatigue-related crashes, FMCSA found that banning the 11th hour would reduce crash-related damages by about 0.3%, worth about $60 million annually.

(V).2 Challenges to the Analysis

This original analysis was challenged in several ways. First, petitioners questioned the use of a function that combined the data points beyond 12 hours and treated them as though they fell near hour 17 rather than at some other point on the graph (e.g., at 13 hours).

Second, the reason for dividing the predicted fatigue levels from the TOT function by the average fatigue-related crash rate was questioned, with the implication that this approach reduced the apparent impact of fatigue.

Third, the value used to divide through the predicted fatigue levels was criticized as being based on TOT hours 1-11, rather than the hours 1-10 that would be allowed in the alternative that eliminated the 11^{th} hour.

(V).3 Responses to Challenges to the Statistical Approach

This section presents FMCSA's responses to the challenges listed above, and the revisions to the statistical analysis that were made after reexamining the issue.

(V).3.1 Use of an Estimated Function

The need to fit a function to the data, rather than use the average probabilities of fatigue-related crashes seen in the data, was a reasonable choice given the very small amount of data at high TOT levels. A review of the TIFA data from 1991-2002, shown in Exhibit (V)-2, helps to show this point. The 1991-2002 data give, for each hour of driving, the total number of crashes and the total number of crashes that were deemed fatigue-related. For example, in the eleventh hour of driving, there were a total of 94 crashes, of which 9 crashes (9.6 %) were fatigue-related. Of interest is the relationship between the number of hours of driving and the probability that a crash in that hour is fatigue-related.

For many of the TOTs, the observed proportion of crashes that were fatigue-related is not a good estimate of the long run probability of future crashes being fatigue-related. If the probability of a fatigue-related crash is low, and total number of observed crashes is relatively small (say, a few hundred or less), then the observed proportion will be a poor estimate of the true proportion because the observed proportion will have a large variance. This is shown by the last four columns in Exhibit (V)-2, which give 95% and 99% confidence intervals for the true proportions based only on the observed proportions

Exhibit (V)-2
1991-2002 TIFA Crash Data Showing Confidence Intervals

TOT (Hour of Driving)	Total Fatigue-Related Crashes	Total Crashes	Percentage of Crashes That Were Fatigue-Related	95% Confidence Interval for Percentage*		99% Confidence Interval for Percentage*	
				Lower	Upper	Lower	Upper
1	102	10412	0.98%	0.80%	1.19%	0.75%	1.26%
2	94	5947	1.58%	1.28%	1.93%	1.19%	2.05%
3	65	4325	1.50%	1.16%	1.91%	1.07%	2.05%
4	68	4216	1.61%	1.25%	2.04%	1.16%	2.18%

Exhibit (V)-2 1991-2002 TIFA Crash Data Showing Confidence Intervals							
TOT (Hour of Driving)	**Total Fatigue-Related Crashes**	**Total Crashes**	**Percentage of Crashes That Were Fatigue-Related**	**95% Confidence Interval for Percentage***		**99% Confidence Interval for Percentage***	
5	62	3028	2.05%	1.57%	2.62%	1.44%	2.81%
6	44	2798	1.57%	1.14%	2.11%	1.03%	2.28%
7	39	1501	2.60%	1.85%	3.53%	1.66%	3.85%
8	48	1668	2.88%	2.13%	3.80%	1.93%	4.10%
9	21	641	3.28%	2.04%	4.96%	1.74%	5.54%
10	22	495	4.44%	2.81%	6.65%	2.40%	7.40%
11	9	94	9.57%	4.47%	17.40%	3.42%	20.05%
12	10	115	8.70%	4.25%	15.41%	3.31%	17.70%
13	8	32	25.00%	11.46%	43.40%	8.66%	48.92%
14	0	17	0.00%	0.00%	19.51%	0.00%	26.78%
15	1	10	10.00%	0.25%	44.50%	0.05%	54.43%
16	3	10	30.00%	6.67%	65.25%	3.70%	73.51%
17	2	6	33.33%	4.33%	77.72%	1.87%	85.64%
18	1	6	16.67%	0.42%	64.12%	0.08%	74.60%
19	0	2	0.00%	0.00%	84.19%	0.00%	92.93%
20	0	3	0.00%	0.00%	70.76%	0.00%	82.90%
21	1	2	50.00%	1.26%	98.74%	0.25%	99.75%
22	1	2	50.00%	1.26%	98.74%	0.25%	99.75%
23	0	1	0.00%	0.00%	97.50%	0.00%	99.50%
24	1	2	50.00%	1.26%	98.74%	0.25%	99.75%
28	2	2	100.00%	15.81%	100.00%	7.07%	100.00%
31	0	1	0.00%	0.00%	97.50%	0.00%	99.50%
34	3	3	100.00%	29.24%	100.00%	17.10%	100.00%
36	2	2	100.00%	15.81%	100.00%	7.07%	100.00%

*Calculation of confidence intervals use a binomial model of fatigue probabilities for each TOT

at the same hour. These confidence intervals are based on the fact that the distribution of the number of fatigue-related crashes at hour h of driving is a binomial distribution where the number of trials, n, is the total number of crashes at hour h, and the "success" probability is the long run probability that a crash at hour h was fatigue-related. This assumes that the n crashes occurred independently. For example, at h = 11, the observed percentage was 9/94 = 9.6% and the 95% confidence interval is the wide range from 4.5% to 17.4%. For hours 10 or less, the total numbers of crashes are much higher and the confidence intervals are much narrower, but for 15 or more hours of driving the intervals are very wide.

Thus, relying on the percentage of fatigue crashes for individual TOT hours would subject the analysis to great uncertainty, because random factors can cause large changes in measured percentages of small numbers. The data for the 13th hour, for instance, shows 25% fatigue crashes, while the 14th hour shows 0% fatigue; the 11th hour shows 9.6%, while the 12th shows only 8.7%. Clearly, none of these disparate values are themselves precise measures of what would be seen if enough data were available. Much better predictions of the probabilities of crashes being fatigue-related can be obtained by the standard statistical approach of fitting parametric statistical models to all the data, so that the probability is a smooth function of the

TOT. In this manner the probabilities can be estimated more precisely, and can be estimated for all values of h, not just the values in the data. For example we can use interpolation to estimate the probability for 25, 26, and 27 hours of driving, which were not included in the data set but were within the range of driving hours in that set. The need to fit a function to the data, using the data from the large volumes of crash experience at low TOT levels, was in fact recognized by the appeals court in the 2004 decision.[63]

The use of a combined data point at the average TOT and average fatigue crash risk, and the use of a cubic function, was a reasonable approach to the need to fit a function and use the limited data available for high TOT values. It is not true that the analysis would have been improved if, as suggested by Public Citizen, these data points could have been combined and then placed at 13 hours. If there is actually an upward sloping relationship between TOT and fatigue, the average fatigue percentage of a set of crashes at TOT levels generally well above 13 hours will tend to be well above the true fatigue percentage at exactly 13 hours. This approach to using the data beyond 12 hours would therefore have biased the estimated relationship considerably.

(V).3.2 Shortcomings of the Original Estimation Technique

Though the regression approach that was used yields a plausible approximate model, there are several limitations with it. One fundamental limitation with the model is that the estimated probabilities can be outside the possible range from 0 to 1 for some values of h, in particular when h is very large. Thus the model is only consistent over a range of h values. Compare this to the logistic model, which always estimates probabilities between zero and one, because the logit function maps the interval from zero to one into the interval from minus infinity to plus infinity.

A second problem with this model is that the least squares regression model estimates the parameters assuming that all the errors have the same variance. However, the variance of a proportion p is approximately given by p(1-p)/n, if n is the total number of crashes. One way to avoid this problem is to use a weighted linear regression, where the weights are the reciprocals of the estimated variances. Otherwise, the estimated parameter values will still be unbiased (ignoring the various other issues discussed in this section), but they will generally not be the most efficient estimates (i.e., they will not have the lowest possible variance).

A third problem with this model is the treatment of the data for hours 13 and greater. Under this approach, all those data are treated as if the crashes all occurred at the same hour (16.73), even though the actual data has these crashes occurring at different hours. Thus the variability in those data has been ignored. This approach is a reasonable approximation to the actual data but it is not clear from the form of the model whether this general approach would cause an appreciable bias in the estimated relationship. As shown in Section (IV).3.3, the similarity between the cubic model predictions and the predictions of an improved model for h smaller than 12 shows that in this case the bias is small in the range of interest.

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[63] United States Court of Appeals FOR THE DISTRICT OF COLUMBIA CIRCUIT Argued April 13, 2004 Decided July 16, 2004 No. 03-1165 PUBLIC CITIZEN, ET AL., PETITIONERS v. FEDERAL MOTOR CARRIER SAFETY ADMINISTRATION, RESPONDENT, p. 16

(V).3.3 Re-estimation of the TOT Function

To correct the shortcomings of the original cubic regression, we have re-estimated the function using a more appropriate approach. A logistic model was used to predict those probabilities for each hour of driving, also described as the TOT.

Logistic regression is a standard statistical approach that ensures that the predicted probabilities will be between zero and one. The logistic regression takes the form

Logit{Prob (Crash is fatigue-related | crash occurred at hour h of driving)} =
$a0 + a1 \times h + a2 \times h^2 + a3 \times h^3 + \ldots + ak \times h^k$,

where k >= 0 is some integer and the coefficients a0, a1, …, ak are unknown parameters. The logit function is defined as

logit(p) = log{p/(1-p)}, where log denotes the natural logarithm.

We fitted this model to the 1991-2002 data using the method of maximum likelihood. The value of k was found by a sequential procedure under which terms $ak \times h^k$ were added to the model until the score chi-square statistic for the added term was not statistically significant at the five percent level. The selected model was a quadratic model with k = 2:

Logit{Prob (Crash is fatigue-related | crash occurred at hour h of driving)} =
$a0 + a1 \times h + a2 \times h^2$.

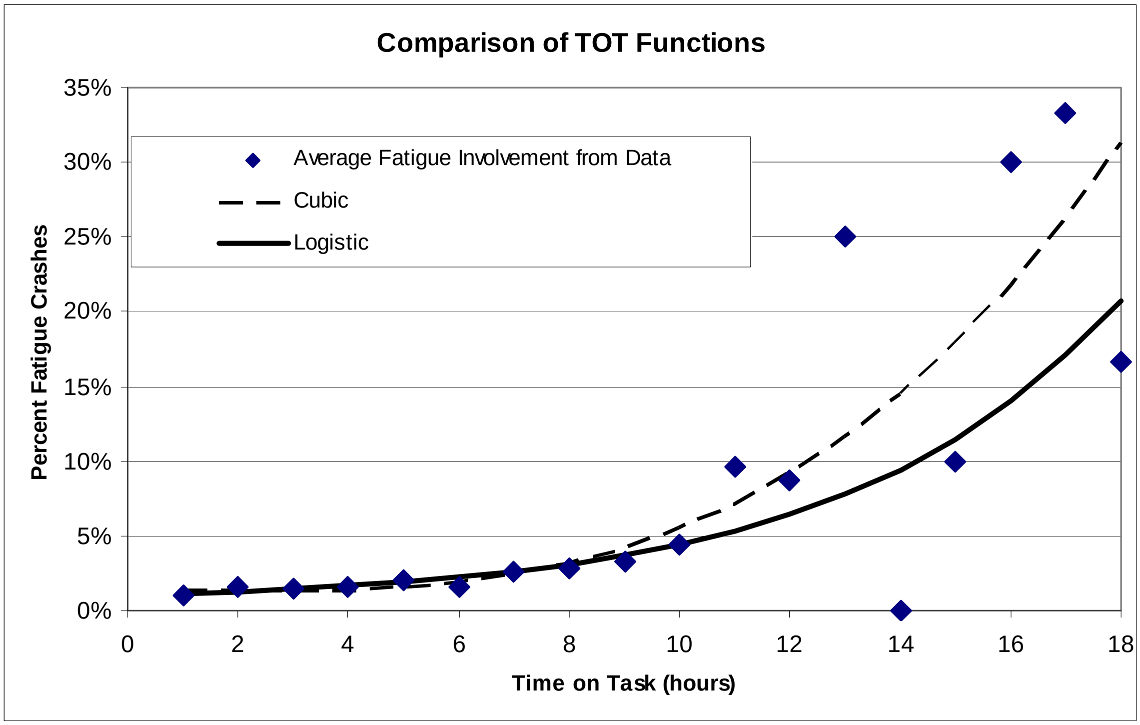
The estimated parameter values and their standard errors are shown in Exhibit (V)-3. The standard error is the estimated standard deviation of the estimated coefficient.

Exhibit (V)-3
Fitted Logistic Model to 1991-2002 Data

Parameter	Estimated Value	Standard Error
a0	-4.6342	0.0911
a1	0.1226	0.0265
a2	0.0034	0.0016

The logistic TOT function is similar to the original cubic function, though somewhat lower at TOT increases. The two functions are compared in Exhibit (V)-4, below.

Exhibit (V)-4 Comparison of TOT Functions



Using the logistic model, the probabilities that a crash is fatigue-related can be estimated for any value of h. The predicted probabilities for h <= 20 and their 95% confidence intervals are given in Exhibit (V)-5. One obvious feature of this model is that the predicted probabilities of crashes being fatigue-related increase as the TOT increases, which is the expected pattern assuming that increased TOT leads to increased fatigue and therefore a greater chance of a crash attributable to that fatigue; the observed probabilities often do not follow this pattern.

Note that the observed percentages of fatigue-related crashes often are not included in the 95% confidence intervals for the predicted percentages. For example, for h = 11, the observed percentage is 9.6% but the 95% confidence interval for the predicted percentage

Exhibit (V)-5
Confidence Intervals for Percentages of Crashes that were Fatigue-related Using the Logistic Model Applied to 1991-2002 TIFA Data

TOT (Hour of Driving)	Observed Percentage of Crashes That Were Fatigue-Related	Predicted Percentage of Crashes That Were Fatigue-Related	95% Confidence Interval for Predicted Percentage	
			Lower	Upper
1	0.98%	1.09%	0.95%	1.25%
2	1.58%	1.24%	1.12%	1.38%
3	1.50%	1.43%	1.30%	1.56%
4	1.61%	1.65%	1.51%	1.79%
5	2.05%	1.91%	1.75%	2.09%
6	1.57%	2.24%	2.03%	2.47%
7	2.60%	2.63%	2.36%	2.93%
8	2.88%	3.11%	2.75%	3.51%

Exhibit (V)-5 Confidence Intervals for Percentages of Crashes that were Fatigue-related Using the Logistic Model Applied to 1991-2002 TIFA Data				
TOT (Hour of Driving)	**Observed Percentage of Crashes That Were Fatigue-Related**	**Predicted Percentage of Crashes That Were Fatigue-Related**	**95% Confidence Interval for Predicted Percentage**	
9	3.28%	3.70%	3.23%	4.23%
10	4.44%	4.42%	3.81%	5.12%
11	9.57%	5.31%	4.51%	6.25%
12	8.70%	6.41%	5.35%	7.67%
13	25.00%	7.77%	6.33%	9.50%
14	0.00%	9.44%	7.49%	11.83%
15	10.00%	11.49%	8.85%	14.80%
16	30.00%	14.00%	10.41%	18.58%
17	33.33%	17.05%	12.22%	23.29%
18	16.67%	20.72%	14.29%	29.06%
19	0.00%	25.06%	16.64%	35.92%
20	0.00%	30.11%	19.28%	43.73%

ranges from 4.51% to 6.25%. The predicted results are nonetheless consistent with the observed data because of the large uncertainty in the observed percentages, as shown in Exhibit (V)-2. The following Exhibit (V)-6 demonstrates this point by comparing the confidence intervals for the observed percentages with the confidence intervals for the predicted percentages over the range h = 9, 10, 11, 12, 13, and 14. Except for h = 13, the confidence intervals for the observed percentage contain the confidence intervals for the predicted percentage.

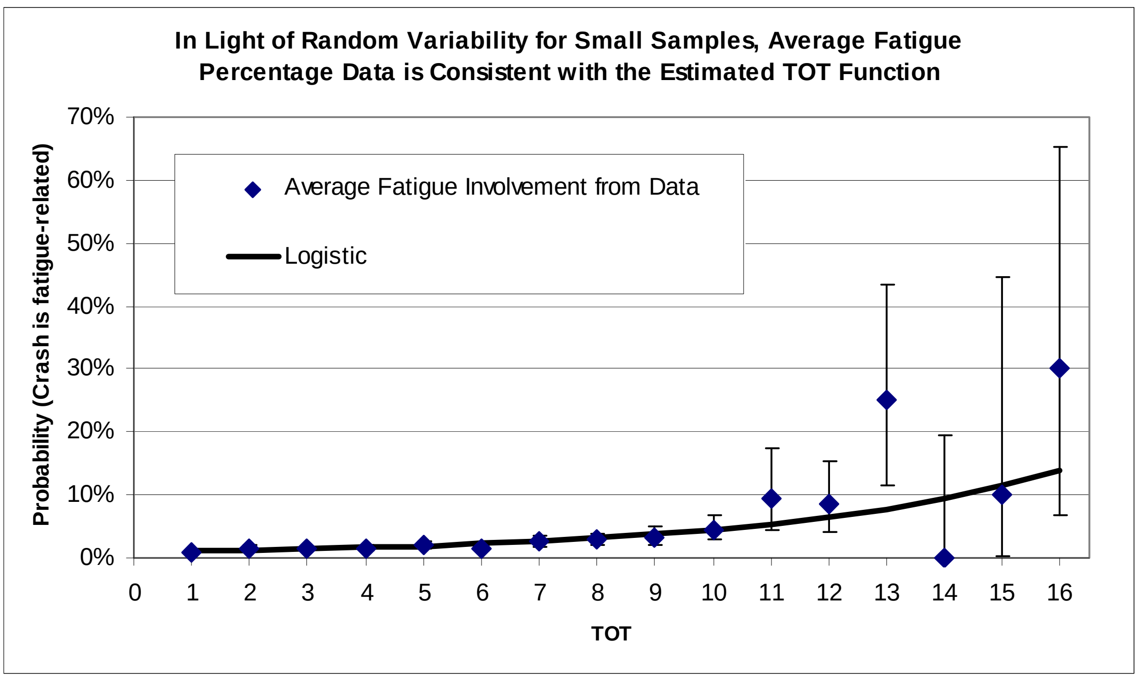
Exhibit (V)-7 displays these concepts graphically; the bars show the 95% confidence intervals for the fatigue-related percentages in individual hours.[64]

"Booststrap" Analysis of the Difference in Predicted Probability for Hour 11 and Mean Predicted Probability for Hours 1 to 10 The predicted probabilities in Exhibit (V)-5 can be used to calculate the difference between the mean probability for hours of driving 1 to 10 and the probability for hour 11, which is a measure of the change in fatigue-related crashes that would occur if an hour of driving were shifted from the 11th hour to an average of the earlier hours. The mean probability for hours of driving 1 to 10 equals 2.34% and the probability for hour 11 equals 5.31%, giving a difference of 2.97%. Since this estimated difference is a complicated function of the parameters a0, a1, and a2, the uncertainty of the estimated difference cannot be calculated analytically. For this calculation we used a bootstrap simulation technique, as described below.

[64] The relationship between TOT and fatigue seen in these data might be related, in part, to difference in sleep, work, and time awake, which are in turn correlated with TOT. Unfortunately, the data set on which this analysis was based did not include information on these other variables, so it was not possible to determine the independent effect of TOT hold other variables constant. Because some of the apparent effect of TOT is likely to be due to these other variables, we consider the functional relationship used here to be a conservative measure of the size of the independent effect of TOT (in that the function is likely to overstate that effect). Also, to the extent that the 2003 HOS increased opportunities to sleep and reduced opportunities to drive after long hours awake, the current relationship of TOT to fatigue might be weaker than it appears here.

Exhibit (V)-6 Comparison of 95% confidence intervals for observed and predicted percentages using 1991-2002 data.						
TOT (Hour of Driving)	**Observed Percentage of Crashes That Were Fatigue-Related**	**95% Confidence Interval for Observed Percentage**		**Predicted Percentage of Crashes That Were Fatigue-Related**	**95% Confidence Interval for Predicted Percentage**	
		Lower	**Upper**		**Lower**	**Upper**
9	3.28%	2.04%	4.96%	3.70%	3.23%	4.23%
10	4.44%	2.81%	6.65%	4.42%	3.81%	5.12%
11	9.57%	4.47%	17.40%	5.31%	4.51%	6.25%
12	8.70%	4.25%	15.41%	6.41%	5.35%	7.67%
13	25.00%	11.46%	43.40%	7.77%	6.33%	9.50%
14	0.00%	0.00%	19.51%	9.44%	7.49%	11.83%

Exhibit (V)-7
Comparison of Logistic TOT Function to Confidence Bounds around Fatigue Percentages



The raw data contains results for a total of 35,341 crashes (not including cases with missing values for TOT or fatigue), of which 10,412 occurred in hour of driving 1, 5,947 occurred in hour of driving 2, and so on. For each of 1,000 bootstrap simulations we used the fitted logistic model to simulate the 35,341 crashes, deciding for each crash whether or not it was fatigue-related. Thus for the first simulated crash in hour of driving 1, the logistic model predicts that the probability of being fatigue-related equals 1.09% (Exhibit (V)-5) so this crash is given a 1.09% probability of being fatigue-related. Similarly for the remaining 10,411 crashes in hour of driving 1. Thus the simulated number of fatigue-related crashes in hour of driving 1 has a binomial distribution with 10,412 trials and “success” probability 1.09%. A similar calculation applies to all the other crashes in this first bootstrap simulation giving a total of 35,341 simulated crashes (either fatigue-related or not fatigue-related). The logistic model with k = 2 was fitted to the simulated data and the predicted difference between the mean probability for hours of driving 1 to 10 and the probability for hour 11 was calculated for this fitted model. This procedure was repeated for 1,000 bootstrap simulations, producing 1,000 estimated differences ranging from 1.93% to 4.03%. Standard statistical theory shows that this distribution of 1,000 differences will be a good approximation to the true uncertainty distribution of the difference. Therefore we can estimate a 95% confidence interval for the difference as the range from the 26th highest difference to the 975th highest difference, which was 2.32% to 3.65%, since there are 25 + 25 = 50 differences (50/1000 = 5%) outside of this range. Similarly we can estimate a 99% confidence interval for the difference as the range from the 6th highest difference to the 995th highest difference, 2.15% to 3.91%, since there are 5 + 5 = 10 differences (10/1000 = 1%) outside of this range. See Exhibit (V)-8 for a summary.

Exhibit (V)-8
Bootstrap Confidence Intervals for the Probability of a Crash Being Fatigue-related in Hour 11 Minus the Mean Probability of a Crash Being Fatigue-related for Hours 1 to 10

Estimate	95% Lower Bound	95% Upper Bound	99% Lower Bound	99% Upper Bound
2.97%	2.32%	3.65%	2.15%	3.91%

Analyses of Additional Variables using 1991-2004 Data The logistic modeling approach was also applied to TIFA data for the period 1991-2004. This expanded data set included several variables of interest besides TOT: day of the week; time of day; the number of vehicles involved; and the type of vehicle, PUType = 1 if the vehicle was a truck and PUType = 8 if the vehicle was a tractor-trailer. The additional data made it possible to broaden the analysis of the causes of fatigue, adding interesting insights but not, in the end, changing the TOT analysis itself.

We modeled the number of vehicles involved as either being one (single = 1) or more than one (single = 0). For these analyses we excluded cases where the TOT was not reported, where the vehicle was government owned, or where the vehicle was a daily rental and GVWR was less than class 7. We fitted various logistic models of the form:

Logit{Prob (Crash is fatigue-related | crash occurred at hour h of driving, other crash variables)}
$= a0 + a1\times h + a2\times h^2 + a3\times h^3 + \ldots + ak\times h^k$ + terms for other crash variables.

The value of k was selected using the same sequential procedure as above. The five models investigated, in terms of the crash variables other than TOT, were as follows:

- Model 1: None.
- Model 2: Day of week, Time of day (0 to 24), Single, PUType.
- Model 3: Grouped Days (Mon, Tue-Thu, Fri, Sat-Sun), Time in 3-hour groups, Single, PUType.
- Model 4: Time of day (0 to 24), Single, PUType.
- Model 5: Time of day in 3-hour groups, Single, PUType.

Exhibit (V)-9 presents the results of this expanded analysis, showing the coefficients of the five models fit to TIFA data from 1991 through 2004. Each model was fitted to crash data from 35,558 accidents.

Exhibit (V)-9
Coefficients and Standard Errors for Different Logistic Models Fitted to 1991-2004 Data

		Model 1	Model 2	Model 3	Model 4	Model 5
Variable		**Value (S.E.)**	**Value (S.E.)**	**Value (S.E.)**	**Value (S.E.)**	**Value (S.E.)**
Constant		-4.51 (0.10)	-6.11 (0.10)	-5.93 (0.11)	-6.13 (0.10)	-5.92 (0.11)
Hours of Driving (H)	**H**	0.04 (0.04)	0.20 (0.01)	0.16 (0.02)	0.20 (0.01)	0.16 (0.02)
	H^2	0.01 (0.00)		0.00 (0.00)		0.00 (0.00)
	H^3	0.00 (0.00)				
Day	**Monday**		-0.22 (0.10)	-0.18 (0.09)		
	Tuesday		-0.06 (0.09)			
	Wednesday		0.10 (0.09)	0.02 (0.06)		
	Thursday		-0.05 (0.09)			
	Friday		0.01 (0.10)	0.04 (0.08)		
	Saturday					
	Sunday		0.13 (0.13)			
Time	**Midnight**		0.41 (0.21)		0.43 (0.21)	
	1		0.92 (0.17)	0.67 (0.10)	0.94 (0.17)	0.69 (0.10)
	2		0.83 (0.17)		0.84 (0.17)	
	3		0.90 (0.16)		0.93 (0.16)	
	4		1.30 (0.14)	1.20 (0.08)	1.31 (0.14)	1.22 (0.08)
	5		1.56 (0.12)		1.56 (0.12)	
	6		1.08 (0.14)		1.09 (0.14)	
	7		0.73 (0.16)	0.64 (0.09)	0.73 (0.16)	0.64 (0.09)
	8		0.29 (0.19)		0.30 (0.19)	
	9		0.04 (0.21)		0.03 (0.21)	
	10		-0.55 (0.25)	-0.39 (0.12)	-0.56 (0.25)	-0.40 (0.12)
	11		-0.37 (0.22)		-0.38 (0.22)	
	12		-0.47 (0.22)		-0.48 (0.22)	
	13		-0.61 (0.24)	-0.81 (0.14)	-0.62 (0.24)	-0.82 (0.14)
	14		-1.21 (0.31)		-1.23 (0.31)	
	15		-0.38 (0.21)		-0.40 (0.21)	
	16		-0.51 (0.23)	-0.46 (0.13)	-0.52 (0.23)	-0.47 (0.12)
	17		-0.29 (0.24)		-0.30 (0.24)	
	18		-0.64 (0.29)		-0.64 (0.29)	-0.92 (0.19)
	19		-1.76 (0.56)	-0.92 (0.19)	-1.78 (0.56)	
	20		-0.61 (0.33)		-0.60 (0.33)	
	21		-1.50 (0.49)		-1.49 (0.49)	
	22		0.07 (0.24)		0.07 (0.24)	
	23					
Power Unit Type	**Straight Truck**		-0.14 (0.05)	-0.14 (0.05)	-0.14 (0.05)	-0.14 (0.05)
Number of Vehicles	**Single Vehicle**		2.37 (0.08)	2.37 (0.08)	2.37 (0.08)	2.37 (0.08)

All of the models are logistic of the form shown in the equation below:

$$\log\left(\frac{P}{1-P}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_k X_k \qquad (1)$$

where **P** = Prob(Crash is fatigue-related | X_1, X_2, …X_k), the variables $\mathbf{X_1, X_2, \ldots, X_k}$ are the explanatory variables and the $\boldsymbol{\beta_0, \beta_1, \beta_2, \beta_3, \ldots, \beta_k}$ are the coefficients. This equation can be rearranged in terms of P:

$$P = \frac{1}{1+e^{-(\beta_0+\beta_1 X_1+\beta_2 X_2+\beta_3 X_3+\ldots+\beta_k X_k)}} \qquad (2)$$

For each model, the value of P can be calculated based on the selected values of the explanatory variables and their coefficients using the above equation.
As an example, consider a specific scenario using Model 2. To calculate the probability that a crash is caused by fatigue after driving for 8 hours on Monday at 3 am for a straight truck in a multiple vehicle crash, the following values are needed:

β_0 = -6.11 (constant)
β_1 = 0.2 (coefficient for hours of driving)
X_1 = 8 (crash assumed to have occurred in the eighth hour of driving)
β_2 = -0.22 (coefficient for Monday)
X_2 = 1 (crash assumed to have occurred on Monday)
β_3 = 0.90 (coefficient for 3 AM)
X_3 = 1 (crash assumed to have occurred at 3 AM)
β_4 = -0.14 (coefficient for straight truck)
X_4 = 1 (crash assumed to have involved a straight truck)

All the other terms, including the term for the number of vehicles involved (single or multiple vehicle) have X equals zero and are ignored.

Using equation 2 and the values above, the value of P, after driving for 8 hours on Monday at 3 am for a straight truck in a multiple vehicle crash, for Model 2 can be determined to be

$$\mathrm{P} = \frac{1}{1+\mathrm{e}^{-(-6.11+0.2\times 8-0.22\times 1+0.90\times 1-0.14\times 1)}} \qquad (3)$$

or $1/(1+e^{3.97})$, which is about 1.9%.

The same procedure can be repeated for different scenarios using different models.

Exhibit (V)-10 shows the p-values, which are the probabilities that the estimated effects of the individual variables or groups of variables on the probability of fatigue could have occurred by chance – or in other words, if they add explanatory power to a degree that exceeds what would be expected on the basis of chance. All the variables and groups of variables shown in the table are statistically significant at the five percent level except for the day of the week in models 2 and 3. Thus, any differences across the days of the week in the probability that a crash was caused by fatigue – such as the slightly positive coefficient for Friday seen in Models 2 and 3 – could well be attributable to chance.

Exhibit (V)-10
Test Statistics (Wald Chi-square) and P-values for Each Class Variable for Different Logistic Models Fitted to 1991-2004 Data

Class Variable		Model 2 Test Statistic	Model 2 p-value	Model 3 Test Statistic	Model 3 p-value	Model 4 Test Statistic	Model 4 p-value	Model 5 Test Statistic	Model 5 p-value
Hours of Driving (H)	h	302.55*	0.00	45.19*	0.00	304.99*	0.00	306.76*	0.00
	h^2			3.72*	0.05			3.85*	0.05
Day of Week		7.01	0.32	4.70	0.20				
Time		347.70*	0.00	294.11*	0.00	359.13*	0.00	306.76*	0.00
Number of Vehicles		799.39*	0.00	802.56*	0.00	803.30*	0.00	803.37*	0.00
Power Unit Type		7.05*	0.01	7.76*	0.01	7.20*	0.01	7.92*	0.00

*** Significant (p-value < 0.05)**

The day of week variables in models 2 and 3 were found not to be significant and so were excluded for models 4 and 5. The fact that fatigue does not appear to change systematically throughout the week has some bearing on the question of the accumulation of fatigue with long hours of work over multi-day periods: if drivers tend to take breaks over the weekend, and if the heavy working schedules of truck drivers actually led to substantial increases in fatigue, we would expect to see driving performance deteriorate through the week. The fact that fatigue percentages do not continue to increase as the week goes on casts doubt on the hypothesized source of significant fatigue. By contrast, TOT and time of day were both highly significant predictors of fatigue, which again underlines the idea that a large weekly accumulation of work hours cannot be the only important cause of fatigue.

Based on the Akaike Information Criterion, a statistical goodness-of-fit measure that discounts over-fitted over-parameterized models, the best-fitting model was model 4. However, although adding in the other crash variables improved the fit and also provided interesting information about the effects of time of day and multiple vehicles on the fatigue-related crash probabilities, the new data and new models made little change to the TOT relationship. To demonstrate this point we compare the predicted probabilities in Exhibit (V)-5 with the average predicted marginal probabilities for these five models. The predictions are very similar up to hour of driving 15, after which the differences become a little more pronounced (as shown in Exhibit (V)-11). The average predicted marginal probability for hour of driving h is defined as the average of the predicted probabilities calculated for a new data set where the hour of driving is always h but all the other crash variables are the same as in the 1991 to 2004 data. It can be thought of as the average predicted probability at hour h adjusted for all the other crash variables.

Exhibit (V)-11
Average Predicted Marginal Probabilities

TOT	1991-2002 Data	1991-2004 Data Model 1	Model 2	Model 3	Model 4	Model 5
1	1.09%	1.14%	0.95%	1.02%	0.95%	1.02%
2	1.24%	1.22%	1.15%	1.19%	1.15%	1.19%
3	1.43%	1.35%	1.39%	1.39%	1.38%	1.39%

Exhibit (V)-11 Average Predicted Marginal Probabilities						
TOT	1991-2002 Data	1991-2004 Data				
		Model 1	Model 2	Model 3	Model 4	Model 5
4	1.65%	1.51%	1.67%	1.63%	1.67%	1.63%
5	1.91%	1.73%	2.00%	1.91%	2.00%	1.91%
6	2.24%	2.02%	2.39%	2.25%	2.39%	2.26%
7	2.63%	2.39%	2.85%	2.66%	2.85%	2.66%
8	3.11%	2.86%	3.38%	3.14%	3.39%	3.14%
9	3.70%	3.47%	4.01%	3.71%	4.02%	3.72%
10	4.42%	4.26%	4.72%	4.38%	4.74%	4.39%
11	5.31%	5.26%	5.54%	5.18%	5.57%	5.20%
12	6.41%	6.54%	6.48%	6.12%	6.51%	6.14%
13	7.77%	8.15%	7.55%	7.22%	7.58%	7.24%
14	9.44%	10.17%	8.75%	8.50%	8.80%	8.54%
15	11.49%	12.67%	10.11%	10.00%	10.16%	10.04%
16	14.00%	15.70%	11.63%	11.73%	11.69%	11.79%
17	17.05%	19.32%	13.32%	13.74%	13.40%	13.82%
18	20.72%	23.53%	15.19%	16.06%	15.28%	16.15%
19	25.06%	28.29%	17.26%	18.71%	17.37%	18.83%
20	30.11%	33.51%	19.53%	21.73%	19.66%	21.87%

(V).4 Responses to Challenges to the Application of the Function

This section first explains why, in the original analysis, the estimated fatigue percentages were divided by the averages over all driving hours, and then points out that the particular divisor that is used will, in theory, have no effect on the results of the analysis.

(V).4.1 Division of the Fatigue Percentage by its Average

Dividing the predicted fatigue crash risk by an average value is defensible as a reasonable way to create a TOT adjustment factor that changes relative fatigue values within a set of data without changing the average value of that set. The fatigue model used in the original analysis yielded raw fatigue predictions for each simulated driving hour, but did not take TOT explicitly into account. Suppose these raw predictions happened to average 7% fatigue. To adjust these predictions to account for TOT effects, each simulated hour's fatigue percentage should be multiplied by an adjustment factor based on the TOT fatigue function: the raw predicted value for an 11th hour of driving, for example, should be multiplied by a larger value than for an 8th or a 1st hour.

It would have been possible to use the TOT fatigue function directly as an adjustment factor: raw predicted values for the 11th hours could have been multiplied by 0.072, and those for the 1st hours by 0.014. On average, though, the resulting values would be much smaller than the original values, because the average value of the TOT fatigue function across all hours is less than 0.03. In order to return the typical fatigue value to a more realistic level, the adjusted values would have to be scaled up by close to two orders of magnitude. As an alternative, the TOT fatigue function can first be divided by its average. This step creates an adjustment factor that averages 1.0, with some values above 1 and some below. Using this adjustment factor will take the TOT effect into account while leaving the typical measured fatigue level relatively unchanged.

(V).4.2 Choice of the Divisor

In the original analysis, the TOT adjustment factor was created by dividing the TOT fatigue function by 2.92%, which was the average fatigue level for the first 11 hour seen in the underlying data. This choice was questioned, and it was suggested that the average value of the function for the first 10 hours would have been more appropriate. Because of the details of the analysis, however, and the way the results were scaled, the choice of divisor has, in theory, no effect on the results. In a properly implemented analysis, the results will be the same whether the adjustment factor is the TOT function divided by 2.92%, or by 2.5%, or even by 100%: the predicted change in crashes caused by banning the 11th hour will be the same. In the mathematics of applying the fatigue adjustment factors to both the baseline and policy cases, the divisor used to create the adjustment factor affects the numerators and denominators of a ratio in the same way. Thus, the divisor cancels itself out, and has no effect on the estimate of the relative fatigue crash percentages with and without the 11th hour. This point is demonstrated below, in section (V)-5.1

(V).5 Revisions to the TOT Analysis

This section first shows how the TOT analysis can be described in abstract terms, facilitating the demonstration that the choice of the divisor does not affect the results of the analysis if it is consistently applied. It then shows how this description can be used to correct the original analysis of the benefits of eliminating the 11th hour.

(V).5.1 Mathematical Description of the TOT Analysis

The fact that the estimated effects of TOT are, in theory, independent of the divisor used to create the TOT factor can be shown by describing the analysis in abstract terms. This description also clarifies the steps that need to be taken to adjust the results for revisions to the TOT function.

One important element in the analysis is that the modeled fatigue crash percentages for the baseline runs (in which driving 11 hours was permitted) were scaled by a multiplicative factor to calibrate the fatigue analysis; the scaling factor was chosen to bring the average baseline fatigue level to 7%, which had previously been estimated to be the baseline fatigue percentage under the existing rules. The policy runs, in which only 10 hours were allowed, were scaled by the same factor; comparing these the scaled fatigue crash rates for the baseline and policy runs then provided the estimated change in crashes. Thus, the modeling was not performed to determine the baseline fatigue risk, but only the relative changes in that risk as a result of changing the HOS rules. Mathematically, this procedure is the same as multiplying 7% by 1 minus the ratio of two rates: predicted fatigue in the policy case and the predicted fatigue in the baseline case.

$$P = 7\% * \left(1 - \frac{R^{10}}{R^{11}}\right)$$

where P is the measured percentage change in total crash damages attributable to the policy case compared to the base case, and $\underline{R^{10}}$ and R^{11} are the fatigue percentages in the 10-hour policy case and the 11-hour baseline cases, respectively, measured using the operational and SAFTE/FAST fatigue models (as described in detail in Chapters 3 and 5, respectively) . This expression can also be written

P = 7% * p

where

$p = [1 - \frac{R^{10}}{R^{11}}]$, and is the percentage reduction in baseline fatigue resulting from the policy.

In the absence of any adjustments for TOT effects, R^{11} would be found by running a model of carrier operations over a set of realistic cases (see Chapter 3 for a description of this operational model), and using a fatigue model to estimate the percentage increase in crash risk due to fatigue at each hour (see Chapter 5 for details on the SAFTE/FAST fatigue model). The overall average percentage increases in crash risk for each case could be found by calculating the average crash risk increase after grouping all of the hours by TOT, and then finding the weighted average of these crash risks, weighting by the fraction of all driving done at each TOT level. This concept can be notated as shown below.

$$R^{10} = \sum_{TOT=1}^{TOT=10} (\vec{r}_{TOT}^{10} * \vec{W}_{TOT}^{10})$$

where $\vec{r}_{TOT}^{10}$ is a vector of average risk estimates calculated from the results of the operational and fatigue models, considering each of 10 TOT levels separately, for the policy case, and $\vec{W}_{TOT}^{10}$ is a vector of weights, one for each of 10 TOT levels, expressing the percentage of all driving in the policy case that takes place at different TOT levels (as estimated using the results of the operational model), and summing to 100%.

The summation sign $\sum_{TOT=1}^{TOT=10}$ expresses the concept that the products of the TOT-specific risk estimates and weights are summed over all 10 TOT levels to yield a weighted average risk level for the policy case. Similarly,

$$R11 = \sum_{TOT=1}^{TOT=11} (\vec{r}_{TOT}^{11} * \vec{W}_{TOT}^{11})$$

shows the equivalent calculation for the base case.

If TOT is not considered to be measured by the fatigue model, we would have no reason to expect $\vec{r}_1^{11}$ to be different from $\vec{r}_2^{11}$ or $\vec{r}_{11}^{11}$ – in other words, risk would be statistically independent of TOT. Thus, without any adjustment for TOT, the vectors $\vec{r}_{TOT}^{10}$ and $\vec{r}_{TOT}^{11}$ can be replaced with their expected values, the scalars, r^{10} and r^{11}, which are not dependent on TOT. The expressions become, then,

$$R10 = \sum_{TOT=1}^{10} (r^{10} * \vec{W}^{10}_{TOT}) \quad \text{and}$$

$$R11 = \sum_{TOT=1}^{11} (r^{11} * \vec{W}^{11}_{TOT}) .$$

To adjust these estimates using a TOT function, the risk for each hour's driving is multiplied by a TOT adjustment factor that depends on the TOT level: low TOT levels are associated with reductions in risks, and high TOT levels with increases. The TOT function, estimated using data on fatigue and non-fatigue crashes at different TOT levels, can be notated as f(TOT). If it is divided by a typical fatigue-crash percentage, the adjustment factor becomes

A = f(TOT)/D.

If D is chosen appropriately, then A will average approximately 1: higher TOT levels with have above-average adjustment factors, while low ones will have below-average adjustments.

Incorporating these TOT adjustments, the expressions for the average risk levels in the policy and base cases, respectively, become

$$R10 = \sum_{TOT=1}^{10} (r^{10} * \vec{W}^{10}_{TOT} * f(TOT)/D) \quad \text{and}$$

$$R11 = \sum_{TOT=1}^{11} (r^{11} * \vec{W}^{11}_{TOT} * f(TOT)/D) .$$

Furthermore, the scalars r^{10} and r^{11} can be pulled out of the summation signs, leading to

$$R10 = r10 * \sum_{TOT=1}^{10} (r^{10} * \vec{W}^{10}_{TOT} * f(TOT)/D) \quad \text{and}$$

$$R11 = r11 * \sum_{TOT=1}^{TOT=11} (\vec{W}^{11}_{TOT} * f(TOT)/D) .$$

Using these expressions, we can write the estimated percentage change resulting from the policy, taking TOT into account, as follows:

$$p = 1- \left[\frac{r^{10} * \sum_{TOT=1}^{10} (\vec{W}^{10}_{TOT} * f(TOT)/D)}{r^{11} * \sum_{TOT=1}^{11} (\vec{W}^{11}_{TOT} * f(TOT)/D)} \right]$$

Rearranging terms, this expression can be written as

$$p = 1 - \frac{r^{10}}{r^{11}} * \frac{D}{D} * \left[\frac{\sum_{TOT=1}^{10} (\vec{W}_{TOT}^{10} * f(TOT))}{\sum_{TOT=1}^{11} (\vec{W}_{TOT}^{11} * f(TOT))} \right]$$

The factor (D/D) cancels out, leaving

$$p = 1 - \frac{r^{10}}{r^{11}} * \left[\frac{\sum_{TOT=1}^{10} (\vec{W}_{TOT}^{10} * f(TOT))}{\sum_{TOT=1}^{11} (\vec{W}_{TOT}^{11} * f(TOT))} \right]$$

This exercise shows, first, that the choice of D is immaterial to the results so long as it is used the same way for every TOT level, and for both the base and the policy cases.

In addition, it shows how the TOT functions enter into the analysis: for each TOT level, the function is multiplied by the percentage of driving estimated to take place at that TOT level. The products of the function and the driving percentages are then summed to find the percentage changes in fatigue due to the TOT effect.

If r^{10} and r^{11} were identical, the term r^{10}/r^{11} would drop out as well. This simplification would be the case if the only safety effects of banning the 11th hour were reductions in the percentage of driving at high TOT levels. It is possible that the lower productivity per driver in a case that banned driving in the 11th hour could also lead to somewhat more rest, which could reduce fatigue risk. The implications of that possibility for adjusting the results are that the TOT effect would generate only a fraction of the measured benefits of shifting to shorter hours, and that correcting the TOT analysis will have a smaller effect on total benefits. Thus, assuming that $r^{10}/r^{11} = 1$ will overstate the correction to the results needed for the revisions to the TOT analysis if r^{10}/r^{11} is actually less than 1. For this reason, r^{10}/r^{11} is assumed to be equal to 1 for the rest of this appendix, meaning that the correction to the benefits estimates is likely to give an upper bound for the benefits.

(V).5.2 Estimation of Correction to TOT Benefit Calculation

This section shows how the revised analysis addresses the two problems with the previously estimated benefits of banning the 11th hour: the TOT function was imperfect, and the approach laid out above was implemented incorrectly – all TOT hours should have been adjusted, but only those 8 or greater were given adjustment factors.

It was possible to calculate how these two problems would have affected the estimated benefits of banning the 11th hour by estimating the change in the average fatigue crash risk twice: once with the original approach, and once with a corrected approach. For each approach, this was accomplished by

- estimating the fraction of driving that was done in each TOT hour assuming that driving 11 hours was legal to create the weighting vector $\mathbf{W}^{11}_{TOT}$;
- multiplying $\mathbf{W}^{11}_{TOT}$ by a TOT fatigue adjustment factor, f(TOT)/D, and
- finding the sum of these products;
- repeating these calculations for a case that allowed only 10 hours of driving; and
- finding the percentage change in the fatigue percentages between the 11 and 10 hour cases.

These steps, and the results of the revisions to the analysis, are illustrated below.

The logistic regression discussed above was used to produce a set of predicted fatigue percentages for each TOT; these predictions are illustrated by the height of the bars in Exhibit (V)-12; they range from about 1% fatigue at 1 hour to 5% fatigue at 11 hours. Dividing these values through by the average fatigue rate gives an adjustment factor, shown as the diamonds in Exhibit (V)-13. These adjustment factors range from about 0.5 to about 2.5, and are centered around 1.0.

Modeling of operations under different driving limits yielded an estimate of the distribution of all driving hours by TOT. These estimates are shown in Exhibit (V)-14; the light bars show the distribution of driving under the 11 hour limit, and the darker bars show the distribution under the 10-hour limit.

The weighted average TOT adjustment is found by multiplying, for each hour, the percent of driving by the TOT adjustment. Summing across all 10 or 11 hours yields the weighted average TOT adjustment. This calculation is shown in Exhibit (V)-15 for the revised analysis. Exhibit (V)-16 shows the same calculations for the original analysis, which used the TOT function based on the cubic regression and applied it only to the hours greater than 7.

Exhibit (V)-12
Modeled Fatigue Percentage by TOT

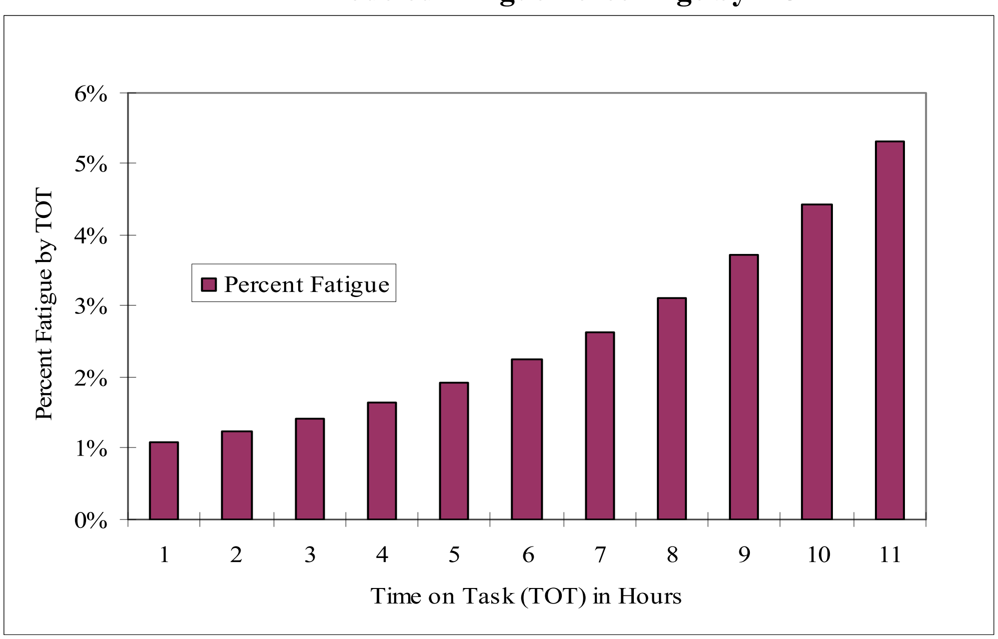


Exhibit (V)-13
Creation of TOT Adjustment Factor Based on Modeled Fatigue Percentages Scaled to Average 1.0

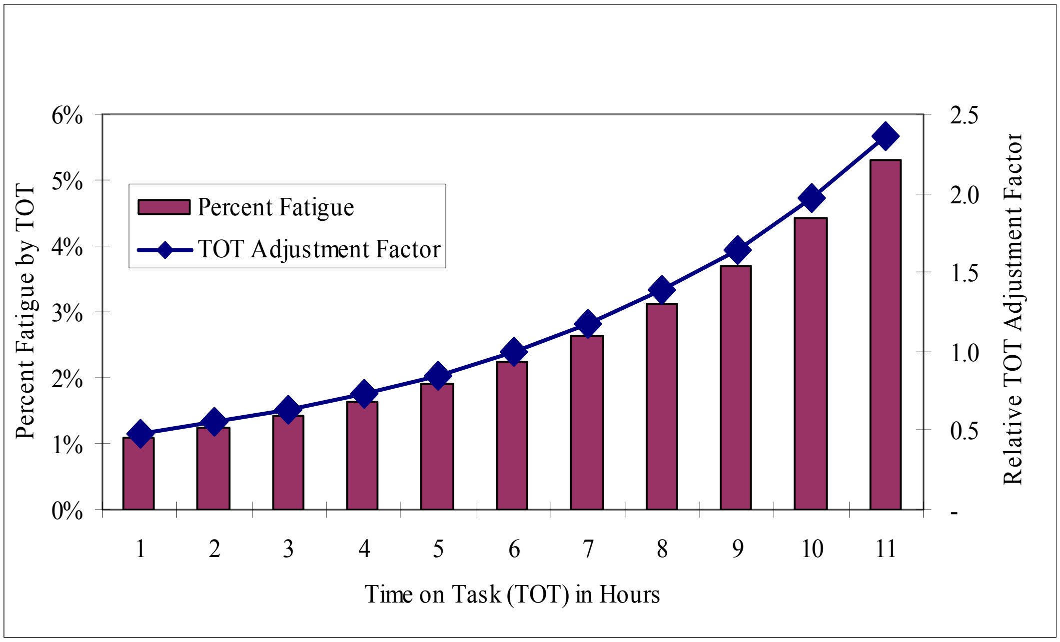


Exhibit (V)-14
Modeled Distribution of Driving Hours

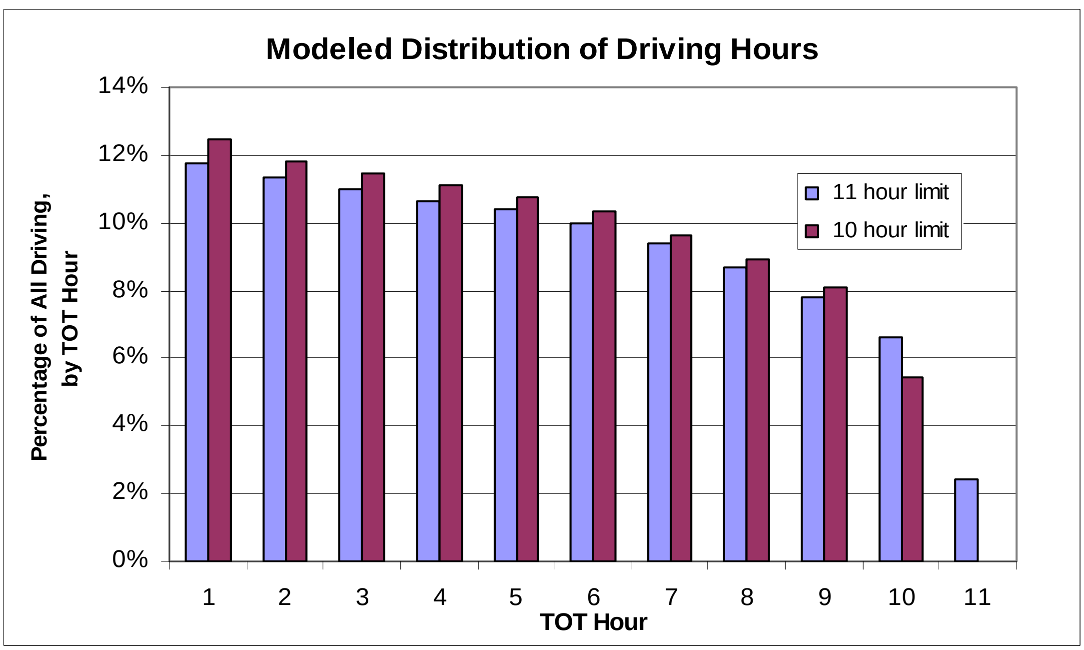


Exhibit (V)-15 Calculation of TOT Impact using the Revised Analysis											
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	
Corrected TOT Adjustment Factor (A'_{TOT})	0.48	0.55	0.63	0.73	0.85	1.00	1.17	1.38	1.64	1.96	2.36	
												Sum
Distribution of Driving 11 hour limit	11.8%	11.3%	11.0%	10.6%	10.4%	10.0%	9.4%	8.7%	7.8%	6.6%	2.4%	100%
10 hour limit	12.4%	11.8%	11.5%	11.1%	10.8%	10.3%	9.7%	8.9%	8.1%	5.4%	0.0%	100%
% Hours w/11 hour limit * A'_{TOT}	0.057	0.062	0.070	0.078	0.088	0.100	0.110	0.120	0.129	0.130	0.057	100.0%
% Hours w/10 hour limit * A'_{TOT}	0.060	0.065	0.073	0.082	0.091	0.103	0.113	0.123	0.133	0.107	-	94.9%
	Measured % Change in Average Fatigue Percentage Due to Shift from 11 to 10 hour Limit:											**5.1%**

Exhibit (V)-16 Calculation of TOT Impact using the Original Analysis											
Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	
Original TOT Adjustment Factor (A_{TOT})	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.05	1.35	1.77	2.31	
												Sum
Distribution of Driving 11 hour limit	11.8%	11.3%	11.0%	10.6%	10.4%	10.0%	9.4%	8.7%	7.8%	6.6%	2.4%	100%
10 hour limit	12.4%	11.8%	11.5%	11.1%	10.8%	10.3%	9.7%	8.9%	8.1%	5.4%	0.0%	100%
% Hours w/11 hour limit * A_{TOT}	0.118	0.113	0.110	0.106	0.104	0.100	0.094	0.091	0.106	0.117	0.056	111.4%
% Hours w/10 hour limit * A_{TOT}	0.124	0.118	0.115	0.111	0.108	0.103	0.097	0.093	0.109	0.096	-	107.4%
	Measured % change in Average Fatigue Percentage Due to Shift from 11 to 10 hour Limit:											**3.6%**

As shown, the correct analysis of the same distribution of hours gives a TOT impact that is 5.1%/3.6% or about 42 percent greater. That means that, instead of the estimated 0.3 percent reduction in LH crash damage, the analysis should have estimated 0.3%*1.42 or about 0.43% reduction in LH damages from eliminating the 11th hour. At a cost of $340 million per 1% change in LH damages, the 0.43% reduction in crashes would provide benefits of $146 million, an increase of 0.13% times $340 million or $44 million in estimated benefits.

(V).6 Comparisons of Revised Benefits to Estimated Costs

This increase of $44 million in benefits still leaves the projected benefits far short of the projected costs. The costs of banning the 11th hour were estimated by finding the average reduction in driver productivity in shifting between a case that assumed the characteristics of the preferred option and a variant that capped driving hours at 10. The average change in productivity, weighting by the fraction of all driving estimated to fall into each operational case, was just over 2.0 percent. [65]

The valuation of the loss of 2.05% in productivity was accomplished using the same method as for the other cost analyses, which found that each percentage point reduction in productivity translated to a loss of $335 million per year.[66] Multiplying the 2.05 percentage point reduction in productivity per driver by the $335 million cost per percentage point yielded an estimated cost of $686 million per year for eliminating the 11th hour. Without the change in the TOT analysis, estimated net costs would be $584 million; with the revised TOT analysis, the net costs are now estimated to be $540 million. Thus, the revisions to the TOT analysis have very little effect on the estimated cost-effectiveness of banning the 11th hour.

The 2005 RIA did present a sensitivity analysis that showed, under extreme circumstances, the net costs could fall from $526 million to $266 million. With the revised TOT estimate, appropriate revisions to the sensitivity analyses, and other updates, the minimum value of the net costs would fall further. There would still be a minimum net cost of approximately $71 million.

[65] This reduction in productivity is close to the industry-wide average percentage of driving in the 11th hour, indicating that a driver unable to use the 11th hour tends to increase waiting time by one hour for each 11th hour of driving lost. This seems reasonable; in many cases a driver will simply stop after 10 instead of 11 hours, leading to the loss of an hour of driving. In some cases that driver can make up the extra hour the next day without exceeding any HOS limits, but in other cases a driver will have to substitute an 8 or 9 hour trip for the preferred 11 hour trip if the preferred load cannot be accepted.

[66] The average per-driver cost of hiring and managing new drivers (and acquiring and operating new vehicles), net of the cost savings for lower driving intensities for existing drivers, was found to be $335 million for each percentage point of reduced productivity for LH drivers. By contrast, each percentage point in industry output is worth several billion dollars, which shows that the cost analysis is measuring the increased cost of supplying the same total services, not the cost to the economy of a reduction in services.