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. As well as 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 of 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, 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.

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[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. 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 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 omitted from 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 ongoing research efforts, one by Ken Campbell of Oak Ridge National Laboratory, and one by a team led by Dr. Paul Jovanis at Pennsylvania State University. Both efforts are being

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[30] Note that only about one-third 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 about 25% of all truck-involved crashes where the truck driver is responsible (or roughly 7 percent of the total).

undertaken specifically for FMCSA, and both were ongoing at the time of this analysis, so this review relies on interim reports and other material provided to FMCSA (as identified in the footnotes) to date rather than formal final reports or published papers. As such, while the results of these studies are considered preliminary, 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, preliminary 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 this 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 being conducted here.

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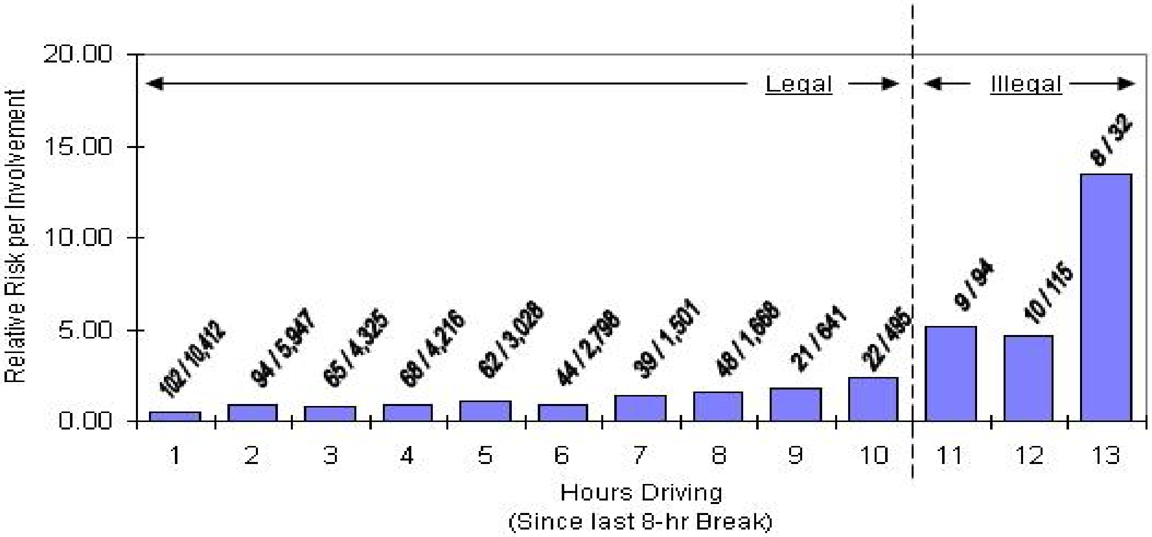
[31] Ken Campbell "Estimates of the Prevalence and Risk of Fatigue in Fatal Crashes Involving Medium/Heavy Trucks Update for 1991-2002 TIFA Files." Letter Report to FMCSA, February 25, 2005

Exhibit 5-1
Relative Crash Risk 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.

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) were 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) will not be available until late 2006. 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 8, of this RIA.

Campbell followed this analysis with a similar analysis of preliminary data (as of December 2004) from the Large Truck Crash Causation Study (LTCCS)[32]. These data covered the period April 1, 2001 to December 31, 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. The preliminary LTCCS data include injury crashes as well as fatal crashes, and it is not clear whether or not the

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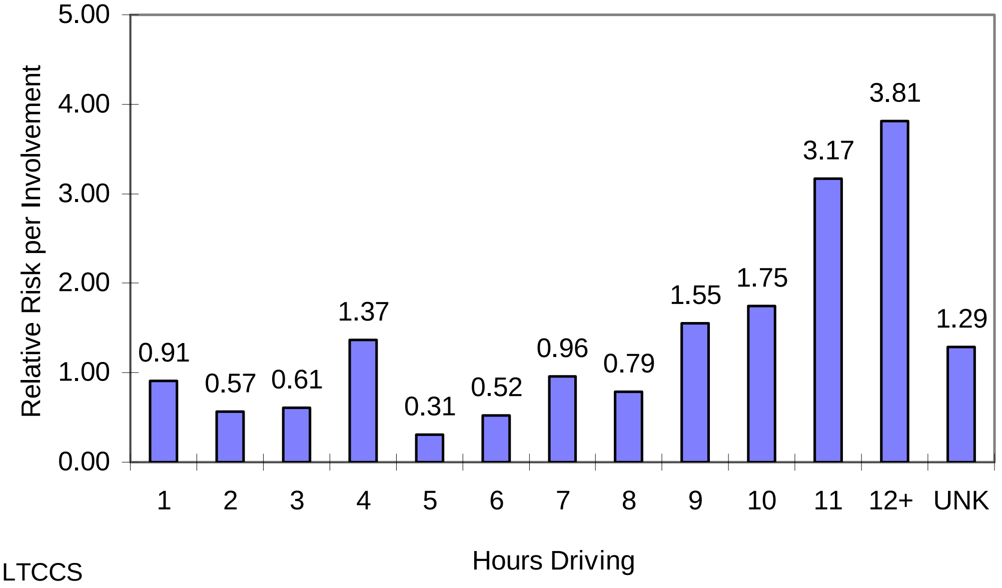
[32] Ken Campbell "Comparing GES and LTCCS Preliminary (December 22) LTCCS File," Letter Report to FMCSA, March 11, 2005.

relative risk data includes the injury crashes. However, it is important to note that the LTCCS data are still preliminary and have not yet been published in final form.

Exhibit 5-2
Relative Crash Risk by Driving Time (Campbell – LTCCS Data)



In contrast to the Oak Ridge/Campbell analysis, the Penn State/Jovanis analysis relies on a sample of data obtained from three cooperating LTL carriers, as described in two interim reports to FMCSA[33],[34] Currently, the sample includes 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 onduty 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 it is representative of only one trucking industry segment (LTL carriers). Additionally, there are very few driver cases involving 11 hours of driving (34, which includes both crash and non-crash cases) are rather low, which is presumably causing 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 Campbell - LTCCS data discussed above. Jovanis also

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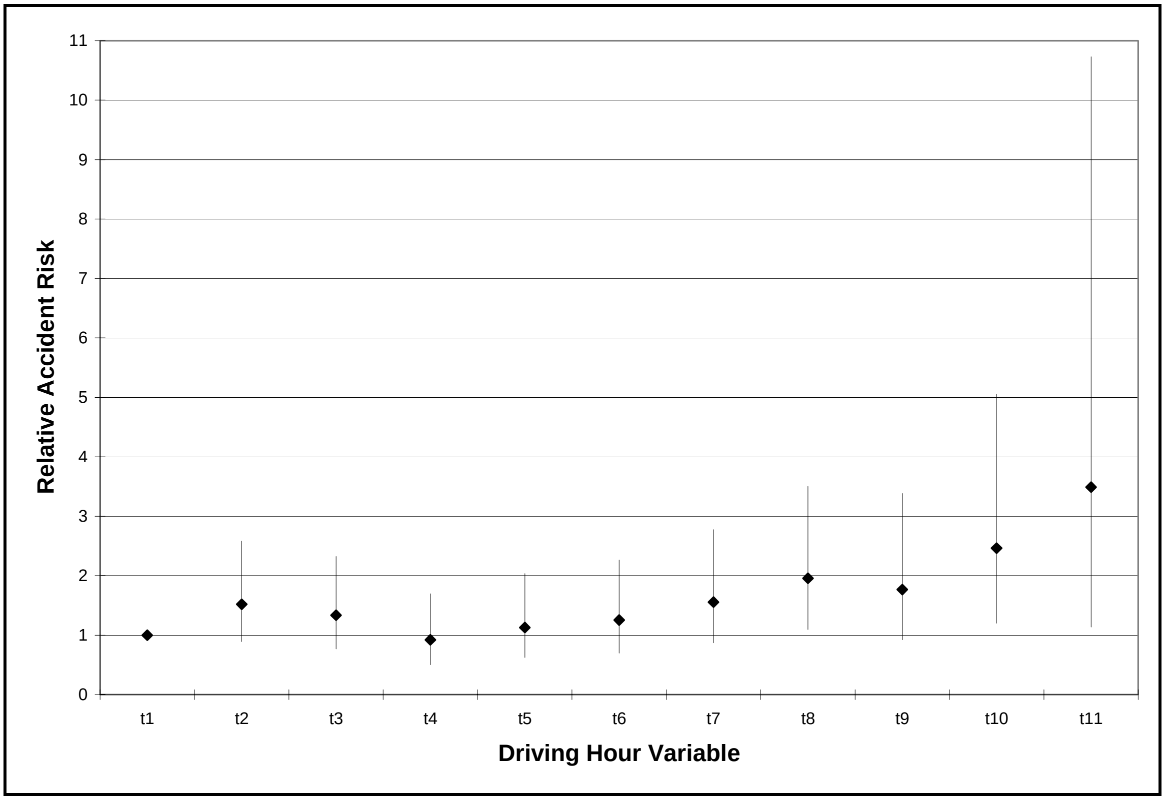
[33] Paul P. Jovannis, Sang-Woo Park, Ko-Yu Chen, “Crash Risk and Hours Driving: Interim Report” Letter report to FMCSA, Pennsylvania Transportation Institute, Penn State University, February 25, 2005

[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.

reports 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. ICF applied the current commercially available version of the FAST/SAFTE 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.

The model applies the results of numerous research studies of each effect to provide a continuous estimate of 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.

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[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.

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 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 FAST/SAFTE 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.

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[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.

- 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 that 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 FAST/SAFTE 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. 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.

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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.

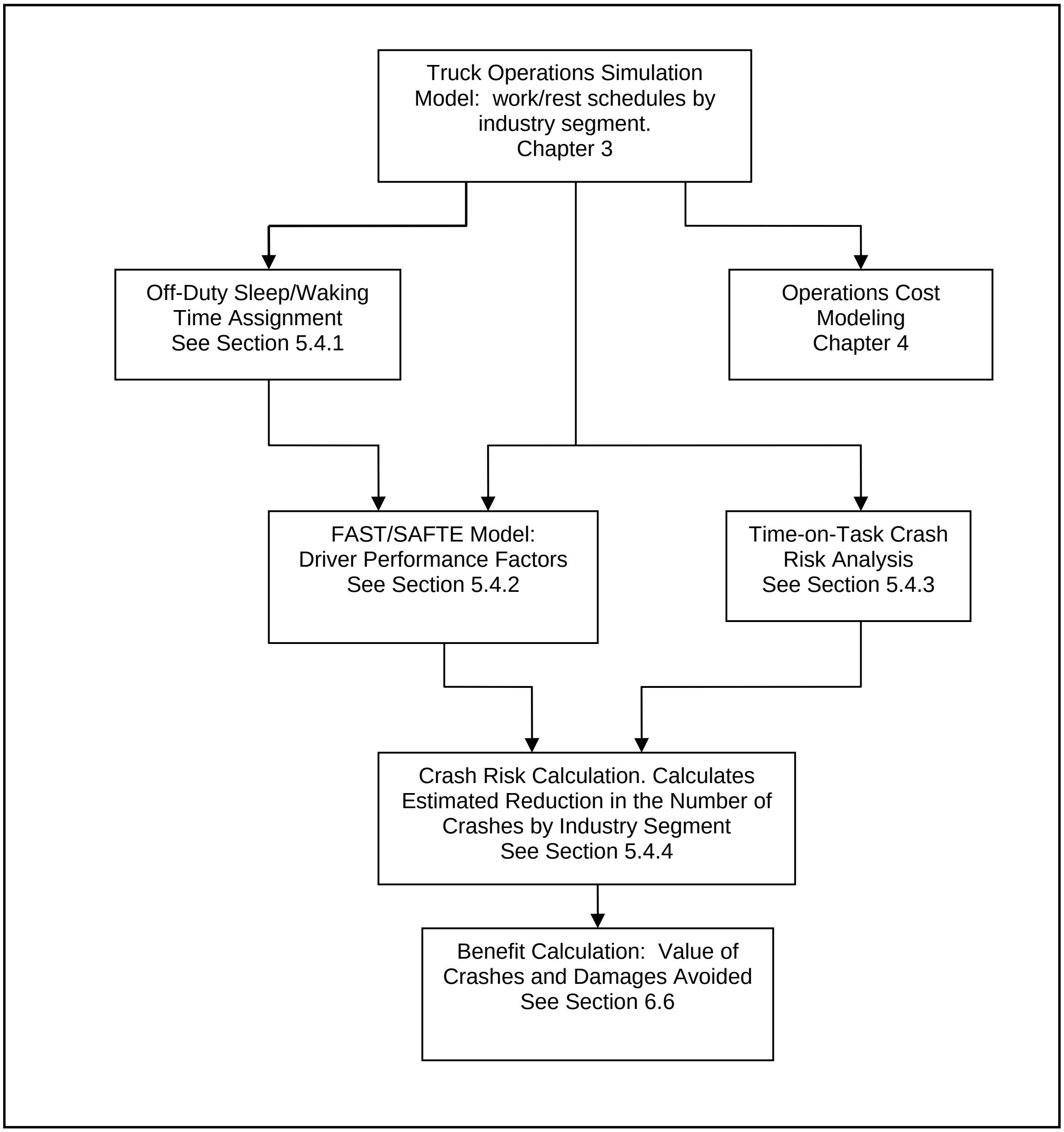
5.3 OVERVIEW OF CRASH AND BENEFIT ANALYSIS

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 FAST/SAFTE 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 FAST/SAFTE 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 FAST/SAFTE 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.

5.4 DETAILED DESCRIPTION OF THE REVISED CRASH AND BENEFIT ANALYSIS

5.4.1 Off-duty Sleep Time Assignment

In order to use the FAST/SAFTE 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 FAST/SAFTE 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. 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, 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 FAST/SAFTE 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 FAST/SAFTE model was the relatively small improvement in driver effectiveness when shifting from the 34-hour restart to a 58-hour restart. To compare these scenarios, 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 5-6 below.

Exhibit 5-6
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 safety model results based on the outputs from the productivity model described in Chapter 3 generally support this conclusion, as shown 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 that 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 a visual example, compare the two FAST model screen shots below.

Exhibit 5-7
Driver on a 'Regular' Schedule

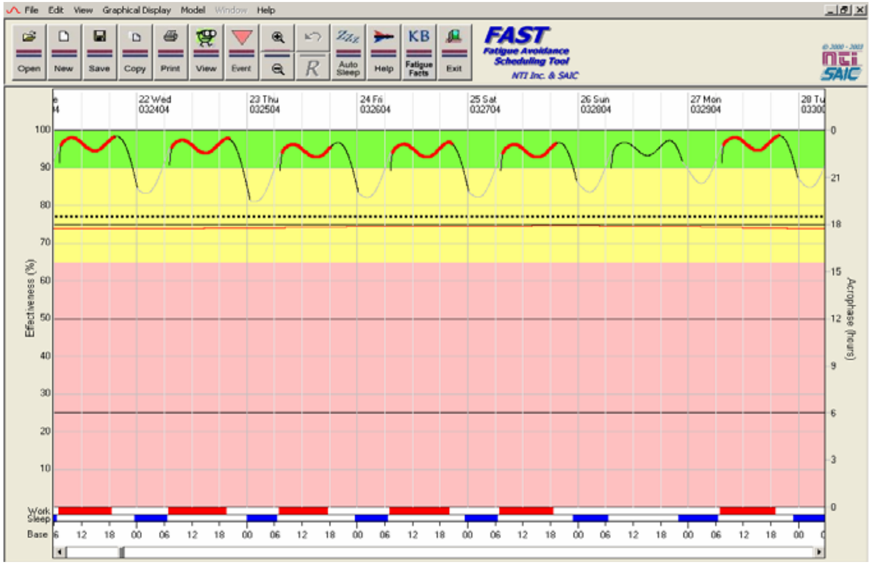
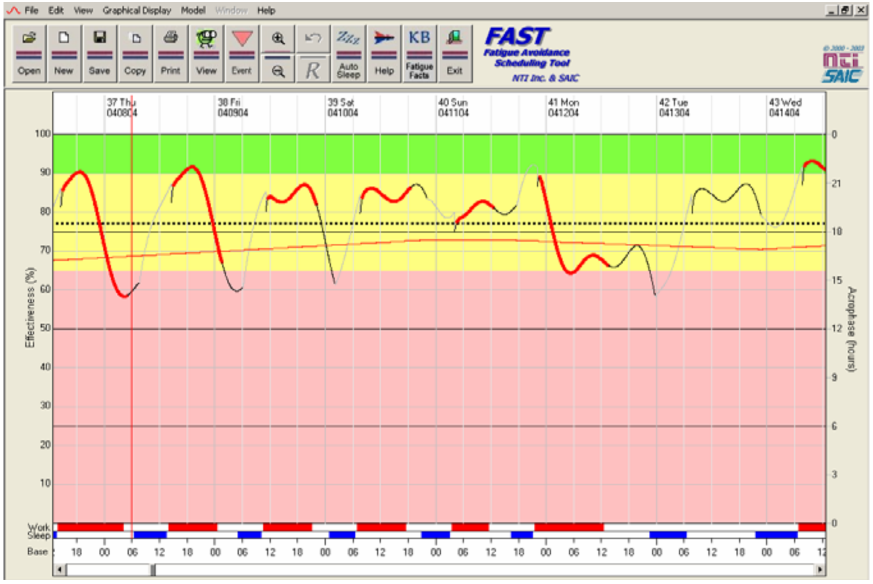


Exhibit 5-8
Driver on a 'Variable' Schedule



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.

Driver Effectiveness – Split v. Continuous Sleeper Berth Periods

Another important observation from the FAST/SAFTE model was the difference in driver effectiveness values based on how drivers took their off-duty periods, and specifically their sleep periods. Of particular interest were drivers who split their sleep period as compared to those that chose not to split. To model these two different drivers, we used the FAST/SAFTE model to calculate the effectiveness of drivers that had 10 hours of on-duty time and 14 hours of off-duty time each day. One driver was given the 14 hour off-duty period in one single block and the other driver was given two 7 hour off-duty blocks. Twelve simulations were run for each driver, each offset by 2 hours, to determine the combined effect of splitting and circadian rhythms. Four weeks of driver data were modeled for this particular analysis. In general, drivers who split their sleep period into two, 7-hour blocks had lower levels of effectiveness than those drivers that took one continuous 14-hour break. Two screen shots from the FAST/SAFTE model show the difference in effectiveness for a driver that chooses not to split and one that does split their off-duty period.

Exhibit 5-9
Driver with Continuous Off-duty Periods

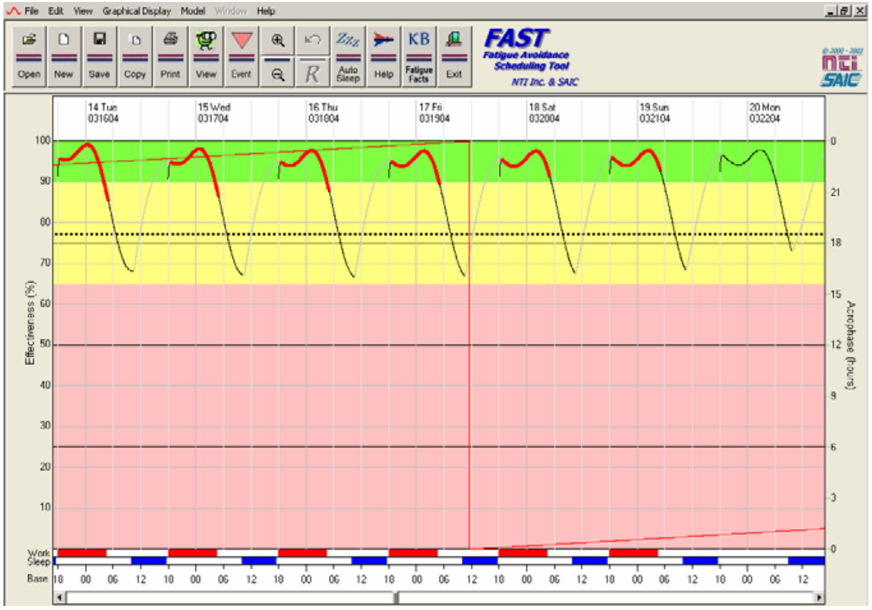
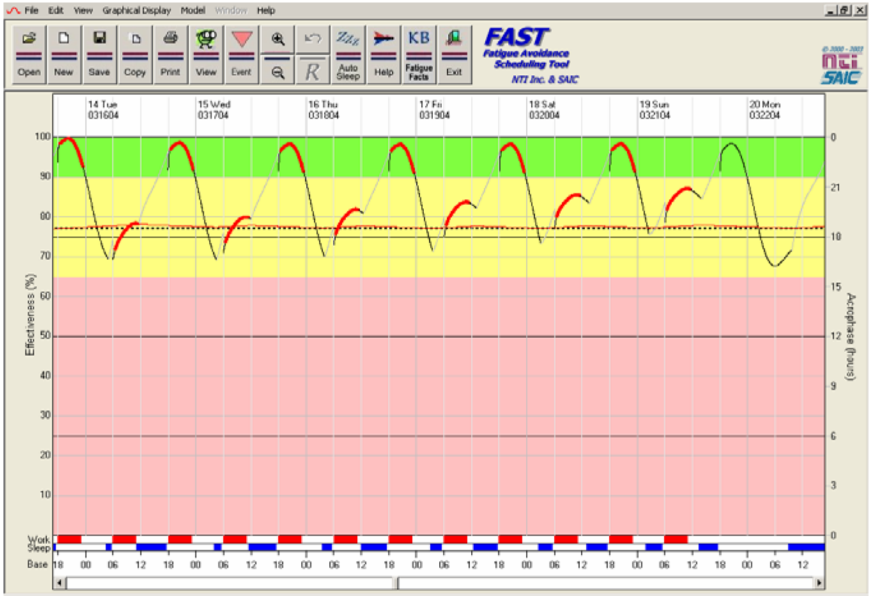
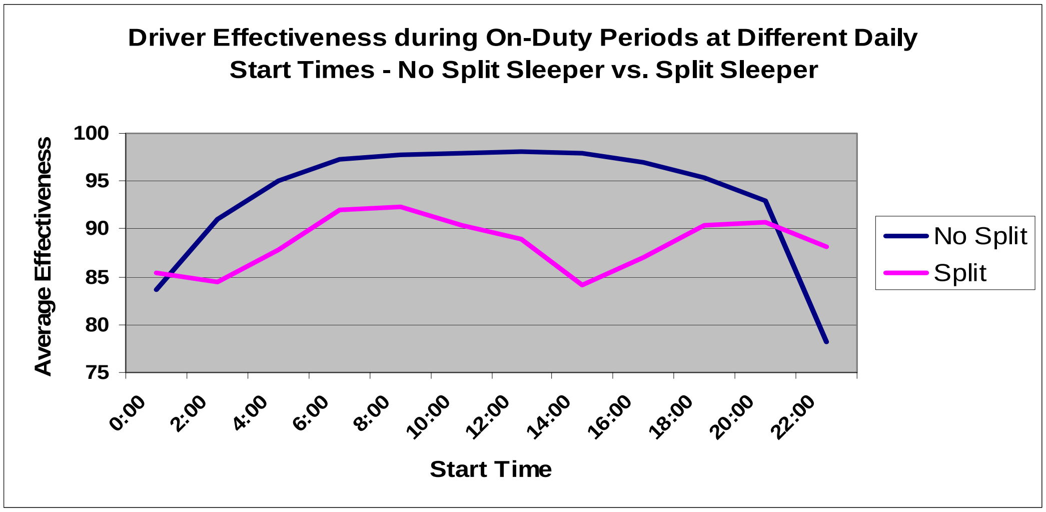


Exhibit 5-10
Driver with Split Off-duty Periods



At different start times over the course of a 24-hour period, the driver that chooses not to split generally has a higher average effectiveness than the driver that splits. However, our modeling shows that drivers beginning their shift between the hours of 22:00 and 0:00 show higher levels of effectiveness if they choose to split their rest period. Exhibit 5-11 summarizes our findings.

Exhibit 5-11
Driver Effectiveness at Different Start Times – With and Without Splitting

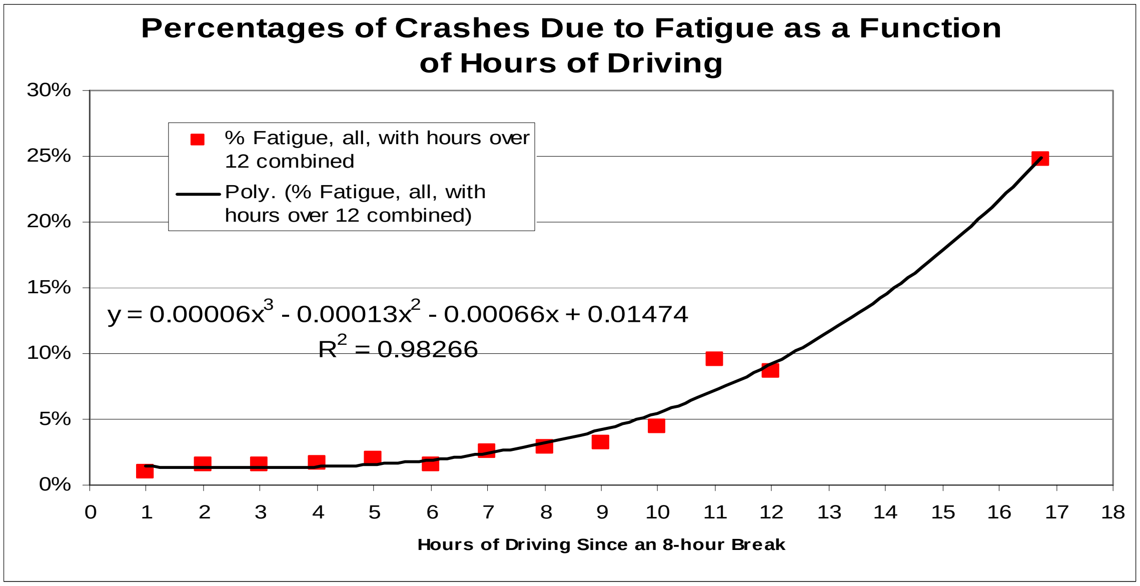


5.4.3. TOT Analysis

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 5-12 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 11th hour may be an outlier. Relative risk data for the 13th 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).

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 11th hour and beyond is very small; (2) because driving beyond 10 hours was illegal under the pre-2003 rule, the relative risk of the subpopulation of commercial drivers admitting to illegal driving during the 11th 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 data 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 11th 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 5-12
Crash Risk as a Function of Hours of Driving



The curve in Exhibit 5-12 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 FAST/SAFTE tool, as described in Section 5.4.4, below.

5.4.4. Crash Risk Analysis

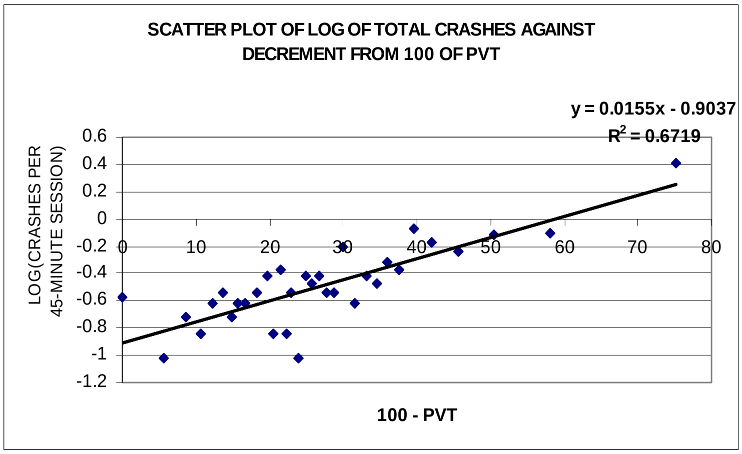
This section explains how the FAST/SAFTE tool outputs and the relationship between crash risk and TOT are combined to provide an estimate of crash risk for each HOS option. The steps in the analysis are as follows:

- Estimate raw crash risk increment from FAST/SAFTE 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 FAST/SAFTE 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 5-12.

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 5-12 and ICF calculations

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

Calculate Raw Crash Risk Increments by Industry Segment. The crash risk increments as calculated by the FAST/SAFTE 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:

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

The calculation is repeated for each HOS option analyzed.