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# TRUCK ACCIDENT FREQUENCY & SEVERITY REDUCTION USING DRIVER FATIGUE RISK ASSESSMENT WITH CIRCADIAN ALERTNESS SIMULATOR

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## Abstract

Heavy truck drivers involved in DOT-recordable or high cost accidents had significantly higher fatigue scores than accident-free drivers on a cumulative fatigue risk scale calculated from driver duty-rest logbooks using a Circadian Alertness Simulator based on the principles of circadian sleep-wake physiology. Implementing a **risk-informed performance-based** safety program, where dispatchers and managers were held accountable for minimizing driver fatigue scores, significantly reduced the frequency and severity of truck accidents.

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Reducing truck accidents on the U.S. highways has been identified as a national priority, and the goal has been set to reduce the approximately 5,000 deaths per year resulting from heavy truck accidents by 50% by the year 2010[1]. To achieve a reduction of this magnitude requires not only that the major preventable root causes of truck accidents be identified, but that effective solutions be developed and then broadly implemented across the trucking industry. Of these major causes, "driver fatigue", or more precisely, driver lapses in attention behind the wheel caused by sleep deprivation has been recognized as one of the leading safety hazards in transportation[2, 3], because a driver impaired by fatigue may not take evasive action (i.e. brake or steer) to avoid or reduce the severity of a potential collision[4,5].

Three major strategies to reduce truck accidents caused by driver fatigue have been attempted. The first was to introduce Hours of Service (HoS) regulations, which since 1938 have limited the consecutive hours of work and driving that a truck driver may perform in a day, and the cumulative total during a 7 or 8 day week[6]. Advances in human

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sleep-wake, alertness and circadian physiology have since shown that such rules have little scientific validity in preventing driver sleepiness[7,8,9], but attempts to reform HoS regulations to incorporate these scientific circadian sleep-wake principles have failed[10].

The second approach has been to try to develop devices which will monitor driver sleepiness or performance and warn drivers of dangerous impairment[11,12], but the technology is expensive and not yet sufficiently reliable to be ready for deployment[13,14].

The third approach, pioneered in Australia, is to allow trucking companies considerable flexibility in hours of work outside the HoS limits, but require them to implement work-rest scheduling practices and policies to minimize driver fatigue, and then measure them by performance-based standards[15]. However, for this third approach to be effective, the managers of trucking fleets need performance measures that provide much more immediate feedback in scheduling their day-to-day operations than the relatively infrequent incidence of accident events. In effect what is needed is a Risk-Informed Performance-Based approach that provides accurate information on the fatigue risk of potential work schedules, so that manager and dispatcher performance in minimizing employee fatigue can be rewarded. (Fig 1).

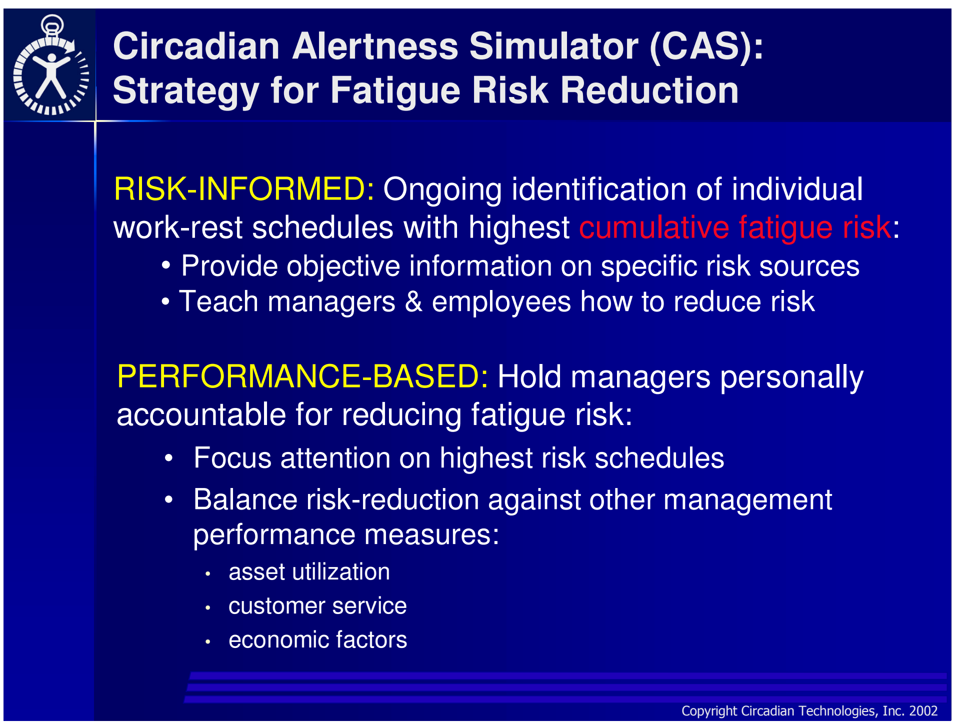


*Figure 1*

Twenty years ago, we reported[16] that applying the principles of circadian sleep-wake physiology[17,18] to the scheduling of work in a round-the-clock industrial shiftwork operation improved the performance and health of employees. However, in comparison to the stable and predictable circadian-based shift schedules that are possible to implement in industrial fixed-location shiftwork operations, the challenge in transportation operations is much more complex. The timing of work and rest is by its nature much more varied and unpredictable in many trucking operations because of the challenges of meeting fluctuating customer demand, varying distances of travel, and the unpredictability of weather and highway congestion.

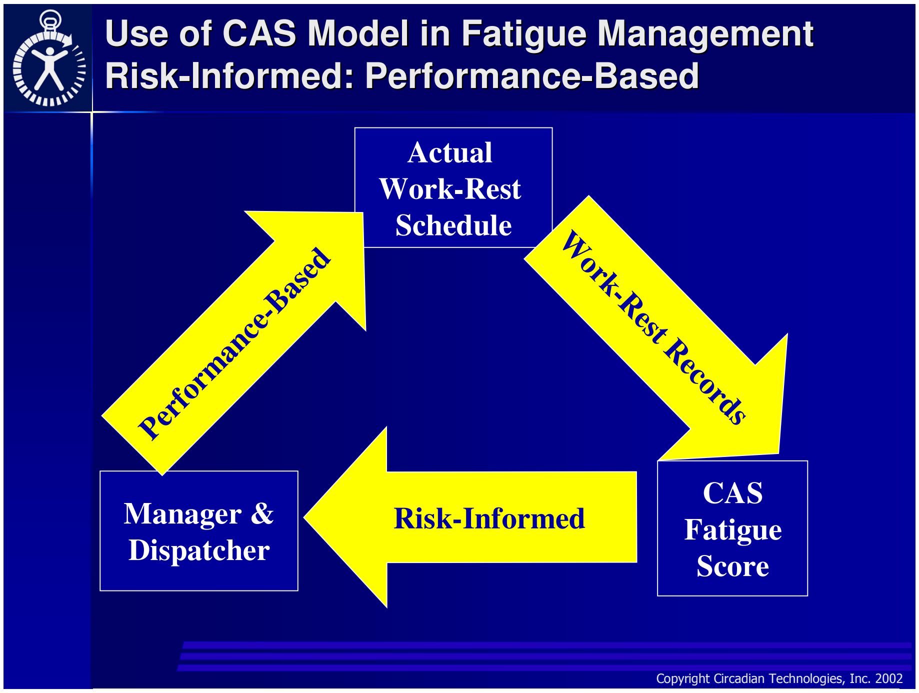


*Figure 2*

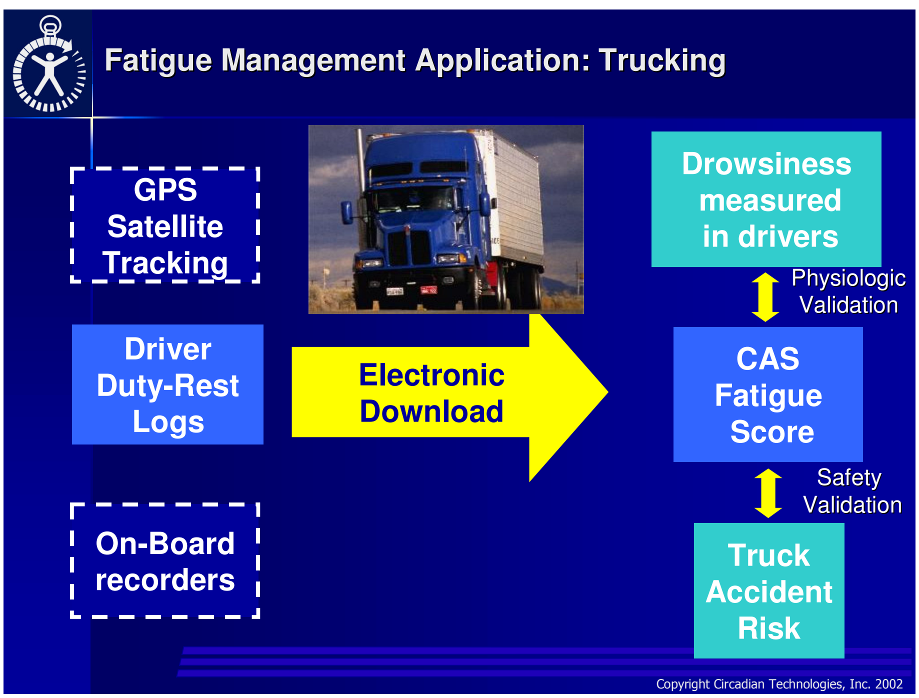


*Figure 3*

We therefore postulated that a practical and effective intervention for reducing the rate of truck accidents would be to provide truck company managers and dispatchers with a fatigue risk scale to enable them to determine the relative risk of accidents due to driver fatigue from any planned sequence of driving and resting hours. Therefore, when planning work hours, they can make **risk-informed** decisions for which they will be accountable in **performance-based** assessments (Figures 2 and 3). We report here that the use of such a fatigue risk assessment tool in a Risk-Informed Performance-Based Fatigue Management Program reduced the rate and severity of heavy truck accidents in a U.S. trucking fleet.

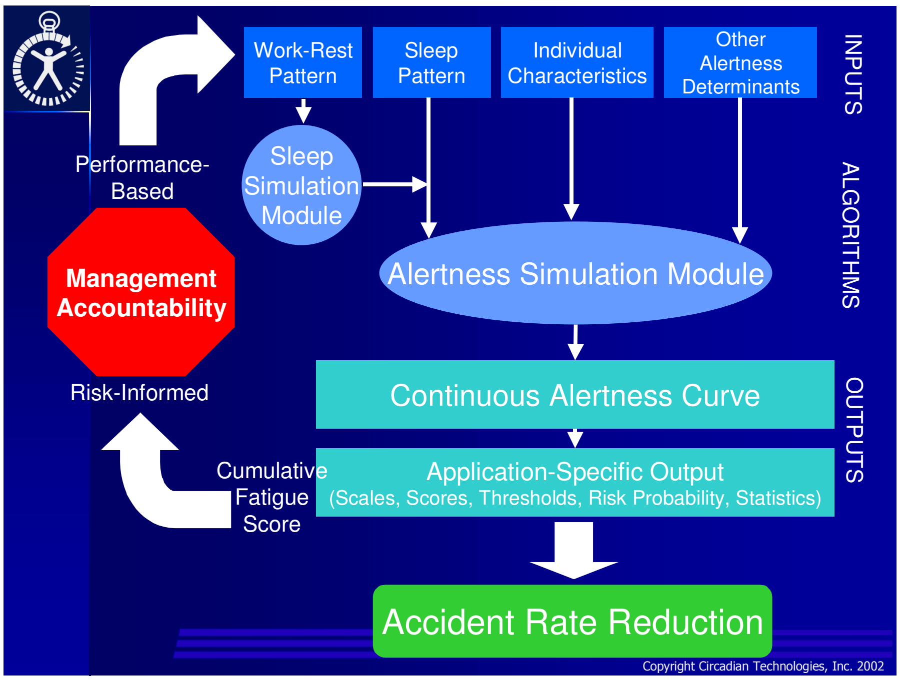


*Figure 4*

This fatigue risk assessment tool uses a mathematical model of sleep and alertness called the Circadian Alertness Simulator (CAS) (Figure 4), and takes advantage of the fact that every trucking company is required by the U.S. Department of Transportation (DOT) to collect driver duty and rest logbook data. CAS uses this logbook data to develop a cumulative fatigue risk scale (0-low, 100-high) of driver average risk of sleepiness on-duty based on the well-established quantitative relationships between the circadian (phase, period, amplitude) and homeostatic (elapsed wake duration since sleep, sleep duration) factors that determine sleepiness. The sleep prediction feature of CAS is based on the two-process model of sleep regulation[20] , where sleep is determined by a circadian and a homeostatic process where sleep is not allowed during duty periods. The threshold positions of the model were determined using actual sleep-wake-work records collected for a month from 29 truck drivers. CAS then uses the estimated sleep-wake cycle to simulate alertness on duty based on the well-established relationships between the circadian functions (phase, period, amplitude), homeostatic functions (sleep, wake duration) and alertness[21]. The free parameters of the model functions for circadian and homeostatic components were determined through an optimization algorithm for data fitting, using 10,000 days of sleep-wake-work data from transportation employees working their normal duties in revenue producing operations.

Because actual human sleep-wake behavior is hard to predict accurately on a particular day in the absence of objective information on off-duty behavior and fluctuates considerably, we choose to compute a cumulative fatigue score over each month, using a weighted sum of daily sleep duration, percentage and time of low alertness during work, average alertness level, variance in alertness level, hours on duty per week and number of recovery breaks allowing two consecutive nights of sleep per week. This fatigue score was scaled so that a Monday-Friday 9AM-5PM daytime-only work schedule scored a 5, and a extreme schedule of consecutive cycles of 36 hours continuously on-duty and 12 hours rest with 1 day off per week (e.g. as seen in medical interns) scored a 95 on a scale of 0 low to 100 high fatigue.

For such a fatigue risk scale to have validity and applicability to accident prevention in the trucking industry we stipulated it must

a) distinguish between duty-rest schedules which are known to induce differing levels of sleepiness in truck drivers,

b) define the statistical distribution of fatigue risk across the wide variety of trucking operations,

c) show a significant correlation between high fatigue scores and accident rates, and

d) show that the rate and severity of truck accidents is reduced when the fatigue score is lowered by modifying driver duty-rest schedules using the principles of circadian sleep-wake physiology.

To address these requirements we first calculated the Circadian Alertness Simulator (CAS) cumulative fatigue scores for four distinctly different duty-rest schedules where sleepiness level had been measured in groups of 20 truck drivers using continuous facial video-recording within the truck cab while they were driving their vehicles in normal revenue-generating service. Figure 5 shows there was a significant correlation (Pearson $r=0.98$ $p<0.05$) between the CAS fatigue score and the mean percentage of the 6-minute segments of video recording independently judged to show a drowsy driver by Mitler et al.[22], in each of the four groups of truck drivers.

Second, we collected driver logbooks for a month from all the drivers (male=852, female=16) from three trucking operations which included less than truck load (LTL), truckload (TL), relay, over the road, local delivery, and sleeper teams located in the eastern, southern and western USA respectively. Figure 6 shows the CAS fatigue scores from these drivers had a mean fatigue score of 40.6 $\pm$20.4 SD.

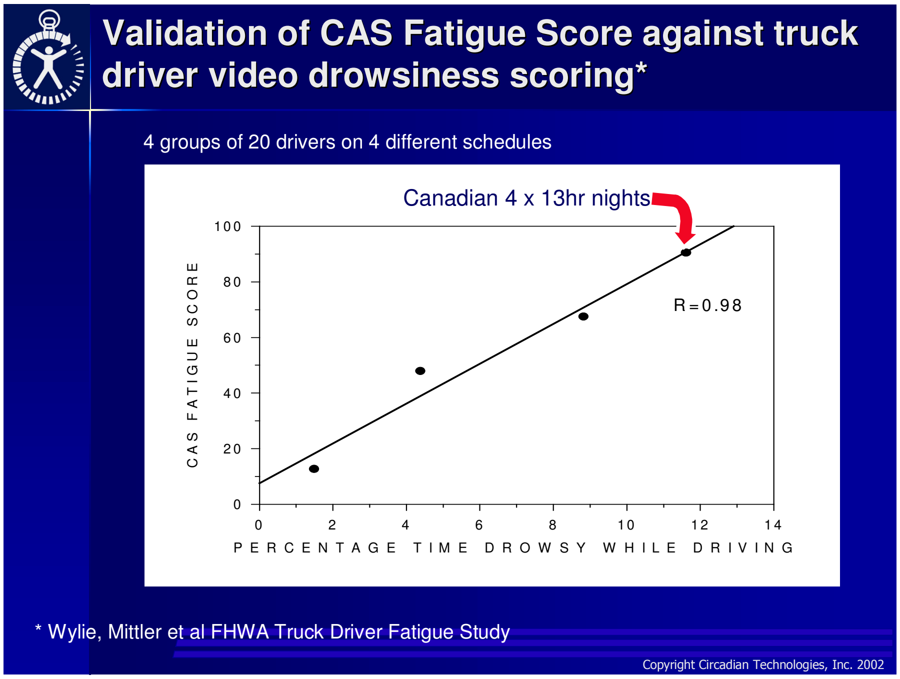


*Figure 5*

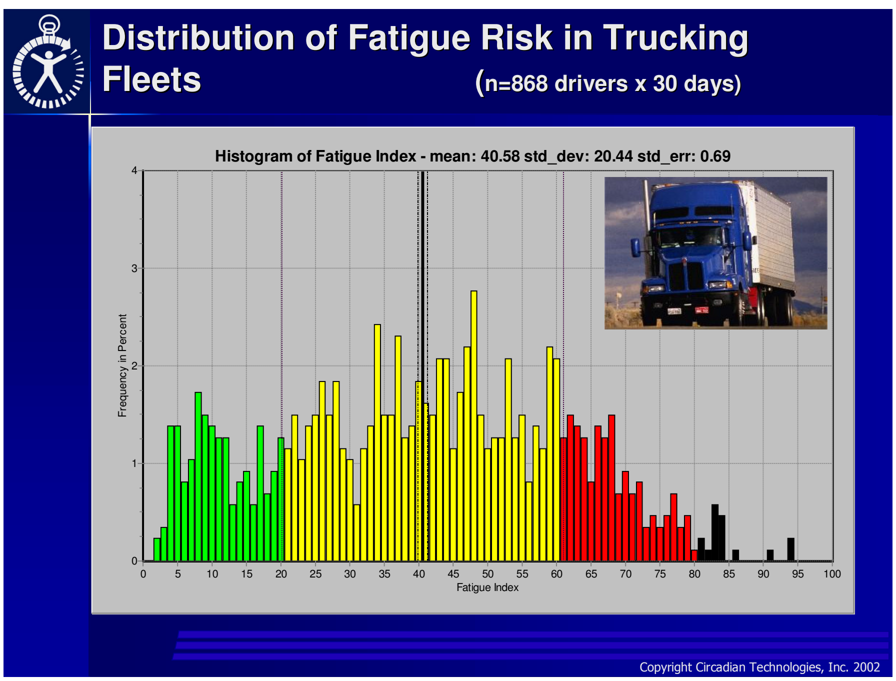


*Figure 6*

Based on these results we defined for the purposes of this study 81-100 as extreme risk (>2 SD above mean), 61-80 as high risk (> 1 SD above mean), medium risk as 41-60 (< 1 SD above mean), reduced risk as 21-40 (< 1 SD below mean) and minimal risk as 0-20 (>1 SD below mean). Using the correlation between video-recorded drowsiness and CAS fatigue score shown in Figure 6, extreme risk (>80) represented greater than 10% of the driving time spent in a visibly drowsy state, whereas minimal risk (<20) represented less than 2% of the driving time spent visibly drowsy.

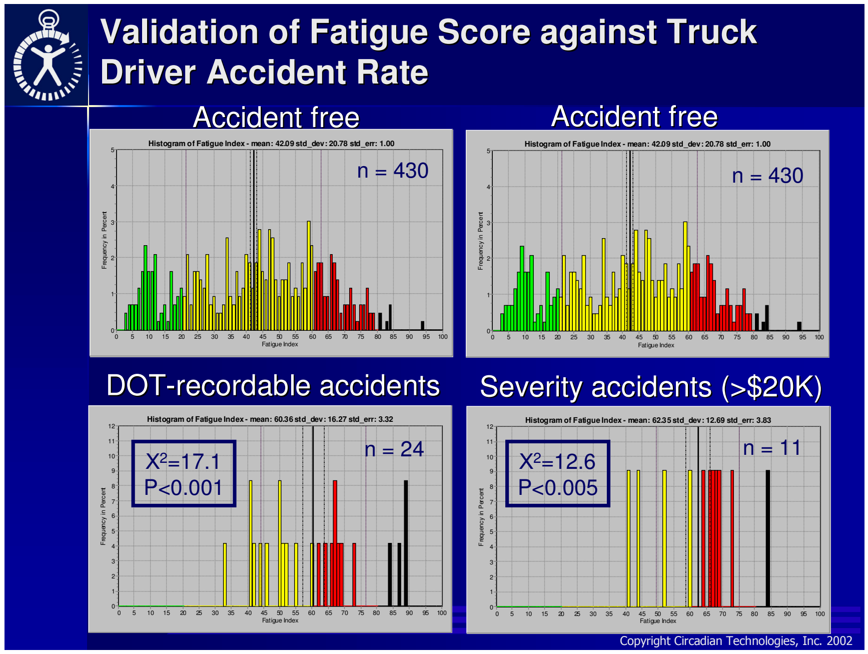


*Figure 7*

Third, the monthly sets of duty-rest logs for all (n=430, 422 male, 8 female) accident-free drivers (mean age: 42 years, range: 23-73) in one trucking operation were analyzed and compared with those from all drivers (mean age: 37 years, range: 22-61) from the same operation involved that year in "DOT recordable accidents"[23] (n=24) and with all drivers (mean age: 33 years, range: 22-53) involved that year in "severity accidents"[24] with insurance claims in excess of $20,000 (n=11) (Figure 7). The CAS fatigue risk score for accident-free drivers averaged 42.1 $\pm$ 1.0 SEM, versus a mean fatigue score of 62.5 $\pm$3.6 SEM for drivers involved in DOT recordable accidents, and mean fatigue score of 63.3 $\pm$4.0 SEM for drivers involved in severity accidents. The higher fatigue scores (represented by a right shift compared to accident-free drivers) was seen both in drivers with DOT recordable accidents, and in drivers involved in severe accidents, indicating a significant relationship between fatigue score and DOT recordability ($\chi 2$=17.1, df=2, p<0.001) and accident severity ($\chi 2$=12.6, df=2, p<0.005). The probability of having a DOT-recordable accident per year of driving in the extreme risk (81-100) group was 0.454, in the high risk (61-80) group was 0.088, in the medium risk (41-60) group was 0.050, in the reduced risk (21-40) group was 0.027, and in the minimal risk (0-20) group was 0, demonstrating an exponential relationship ($R^2$=0.995) between fatigue score and accident risk.

Fourth, to design an intervention to reduce the risk of driver fatigue we took into account that the actual pattern of day-to-day duty and rest hours which impacts driver fatigue is determined by a) the business that the trucking carrier accepts, b) the sequence of trips constructed each workday for each driver by dispatchers, and c) the day-to-day decisions by the truck drivers who alternated work-shifts in driving each truck. We therefore provided the managers and dispatchers in the trucking operation with monthly analyses of the CAS fatigue scores for every driver, and educated the dispatchers on how they could reduce fatigue scores by adjusting the timing and duration of daily and weekly work and rest patterns. These included adjusting the start time and end times of work, providing rest breaks which allowed two consecutive nights of sleep, minimizing night work, avoiding rapid rotations in the starting time of work, and reducing the number of consecutive shifts worked. To re-enforce dispatcher behavior, senior management implemented a policy that made every dispatcher and terminal manager personally accountable for the monthly CAS fatigue scores of the drivers who reported to them.

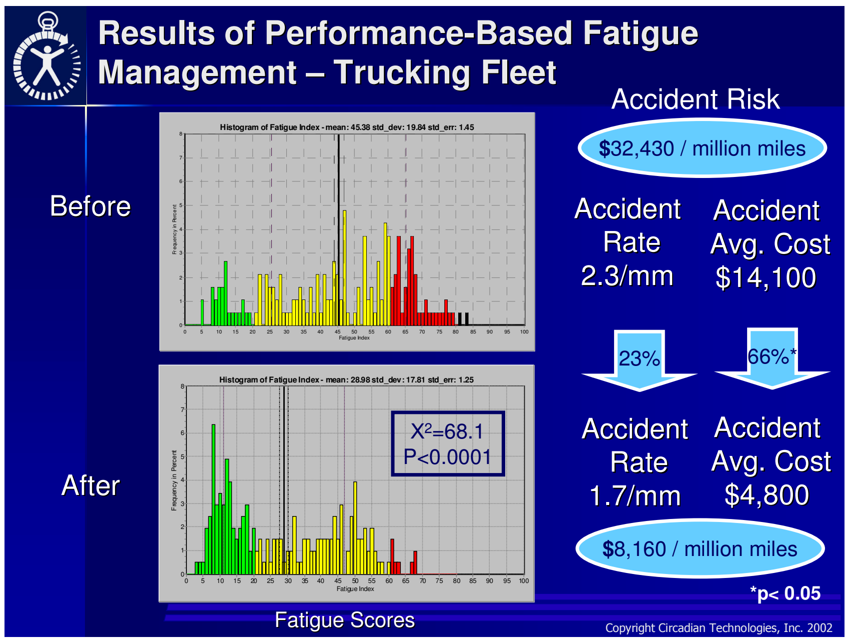


*Figure 8*

Figure 8 shows the shift of CAS fatigue scores that occurred as terminal managers reviewed CAS score results on a monthly basis, and applied techniques in driver scheduling to reduce fatigue score while still providing the 24/7 (twenty-four hour a day/ seven day a week) service required by the customers. The fatigue score fell from a pre-intervention mean of 46.8 $\pm$ 1.4 SEM to 28.9 $\pm$ 1.2 SEM (t =9.41, $p<0.0001$). The percentage of high fatigue risk scores (61 and over) fell from 28.9% to 3.9% and percentage of minimum fatigue risk scores (1-20) increased from 14.9% to 44.6% ($\chi$2= 68.1, df=4, $p<0.0001$). Figures 9 and 10 show the dispatchers achieved this change on average by shifting duty start times later (mode from 0400 to 0500 hr.; mean from 0450 to 0527 hr.; ($\chi$2=840.4, df=11, $p<0.0001$), and the work pattern mode from 6-on/1-off to 5-on/ 2-off (days on: ($\chi$2= 77.0, df=6, $p<0.0001$, days off: ($\chi$2= 170.0, df=3, $p<0.0001$).

This reduction in CAS fatigue score was associated with a reduction in the number and severity of accidents. The total number of truck accidents dropped 23.3% from an average rate of 2.30/million miles for the three years prior to the intervention (April 1998-March 2001) to 1.76/million miles for the year (April 2001 - March 2002) when

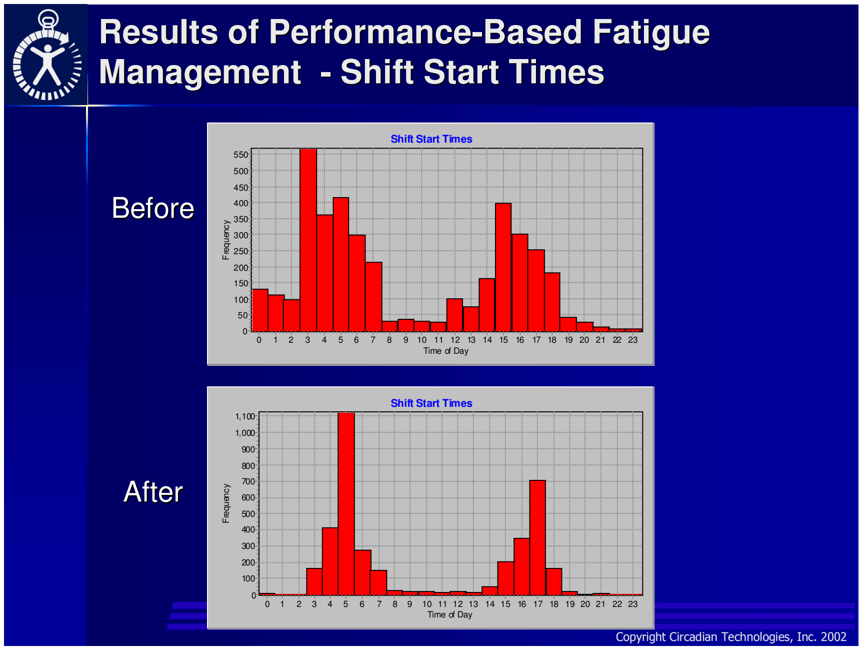


*Figure 9*

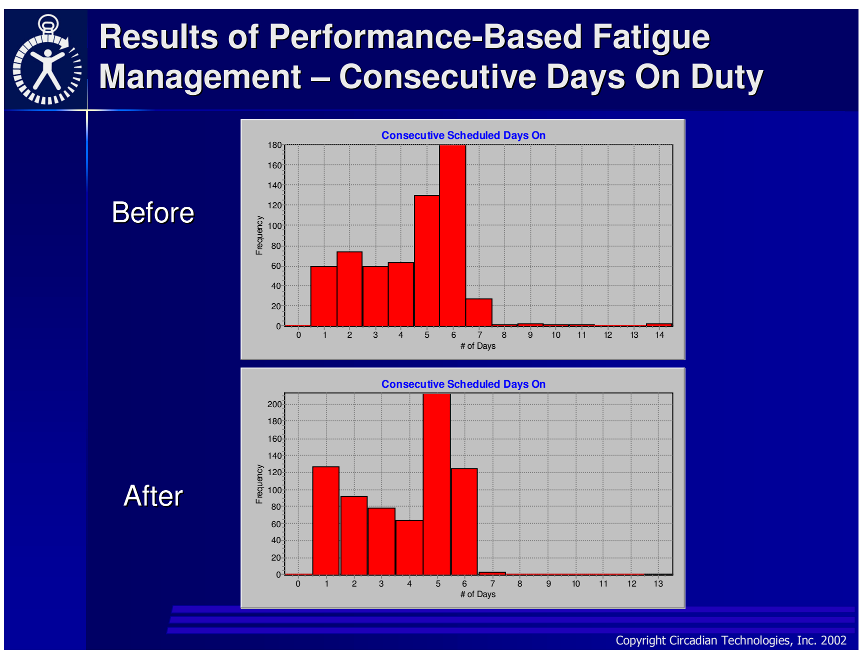


*Figure 10*

CAS fatigue score management was instituted, and the average cost per accident dropped 65.8% from \$14,088 ± 4,307 SEM to \$4,820 ± 1,437 SEM (t -test, $p<0.05$). Severity accidents (over \$20,000 cost) dropped 55% from an average rate of 0.20 /million miles to 0.09 / million miles, and the average cost of the severity accidents dropped 66.7% from \$152,384 ± 40,841 SEM per accident to \$50,809 ± 6,080 SEM per accident over the same time frame (t-test, $p<0.05$). The total cost of loss of attention accidents (defined as collisions, hit rear of another vehicle, loss of control) dropped 80.9% from \$1,187,699/year to \$226,627/year).

Improving the scheduling of work and rest is only one of a number of methods that could have been used to reduce the fatigue risk of these truck drivers. Others include the screening, diagnosis and treatment of sleep disorders such as obstructive sleep apnea to reverse the increased highway accident risk in these patients[25,26] and educating drivers on techniques to obtain better quality sleep and maintenance of alertness on duty. These are unlikely to account for the results reported here since sleep & alertness training alone has been shown to have no lasting effect on shiftworker behavior[27], and the drivers participating in the project were not screened or treated for obstructive sleep apnea during the course of this study.

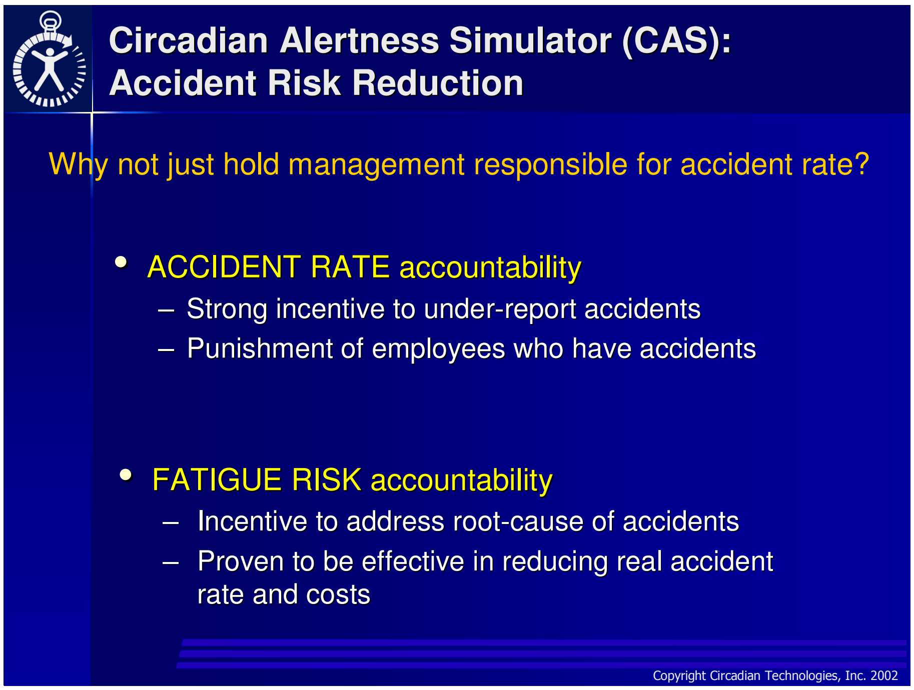


*Figure 11*

Managing by performance-based measure is a well-established method of obtaining tangible results in a business[28,29]. The key is determining the right performance measure (Figure 11). The most obvious measure might have seemed to be accident rate, but accidents are infrequent events and do not provide a measure of the risk of every driver on a month to month basis. Furthermore, implementing management incentives based on reduction in accident or injury rates leads to an under-reporting of accidents, in part because this encourages managers to devise incentives for employees not to report events or injuries[30]. In contrast, using the CAS fatigue score in a risk-informed, performance-based safety program gives managers and dispatchers incentives to address some of the most important causes of driver fatigue, and therefore of fatigue-related highway accidents.

One alternative to performance-based risk management would be to revise the HoS to include prescriptive rules for minimizing truck driver sleep and circadian rhythm disruption, based on duty-rest schedule adjustments such as the dispatchers and terminal managers used here successfully to reduce CAS fatigue scores and accident rates. However, this fails to address the reality that trucking is a highly competitive, low profit business where staying competitive requires the continuous optimization of equipment and human resource utilization in a wide variety of trucking operations and with often changing business conditions, weather, traffic congestion, trip length and customer demands. The trucking industry based its 2000-2001 campaign to defeat the proposed new physiology-based prescriptive HoS regulations on their inflexibility and consequent negative impact on an economically-marginal industry.

We have demonstrated here that driver fatigue can be successfully managed by allowing the trucking dispatchers a trade-off between the various factors which influence sleepiness such as start-times, duration of duty, and number of consecutive days of work.. For example, the modal starting time was shifted from 0400 to 0500 hr., but it was possible for managers to meet the requirements of their customers which might require 0300 hr. start times in some instances, and still achieve lower fatigue scores by simultaneously adjusting other factors such as days-on/days off sequences or hours on duty in order to compensate. On the other hand, the dispatchers could have chosen to reduce CAS fatigue scores by reducing the amount of night work, but elected not to do so because their customers required service at night, and transporting product is much more efficient at night when traffic levels are reduced on the highways.

It would be impracticable to write all this detail into prescriptive regulations on hours of service, and even more difficult to implement it in each different type of real world trucking operation, or to monitor compliance from a regulatory standpoint. In contrast, a regulatory strategy using this performance-based measure (i.e. output rather than input) enables dispatchers and trucking company managers the flexibility to simultaneously balance the optimization of customer service and operating costs, while minimizing the risks of driver fatigue and highway accidents. Once fully validated, this approach may enable the existing Hours of Service regulations to be replaced, or relaxed into outer boundary limits to prevent extreme abuse.

Mathematical models allow the complex set of functions that determine human fatigue to be reduced to an operationally-useful risk score for business managers. The physiological advances in understanding the dynamic relationship between work-rest patterns, cumulative sleep duration and timing and circadian periodicity and phase, and their impact on human alertness and performance have been aided by the development of a number of such mathematical models[31,32,33]. The models have migrated into those that are designed to predict alertness or sleepiness in clinical or research environments, or performance in specialized employee populations (e.g. soldiers). The CAS cumulative fatigue risk scale used here is directed at predicting the probability of fatigue-related accidents in transportation employees. By their nature, models are an imperfect representation of reality, and this is no exception. Continued research and model optimization will be needed using broader populations of truckers and other transportation employees to improve the predictive power of this model and its value in risk management. This approach may also prove valuable in reducing fatigue risk in other shift-working populations.

## REFERENCES and NOTES

[1] Over the past ten years the number of fatalities (truck drivers plus other road users) in heavy truck accidents (defined as vehicles over 10,000 lbs.) on US highways has remained between 4,396 and 5,398 per year. However, because the number of heavy trucks registered and miles traveled have steadily increased, the fatal accident rate has dropped from 3.66 per 100 million miles in Y-1990 to 2.48 in Y-2000 (NHTSA Traffic Safety Facts 2000). The goal announced by DOT Secretary Rodney E. Slater (U.S. DOT Commercial Motor Vehicles Safety Action Plan May 25, 1999) to cut the total number of fatalities in heavy truck crashes by 50% within the next 10 years, would require a decrease in fatalities from 2.48 per 100 million miles in Y-2000 to 0.94 in Y- 2010 (i.e. a 62.1 % decrease) assuming a linear extrapolation of the Y-1990 to Y-2000 increase in vehicles registered and miles traveled. The truck involvement rate would similarly have to fall by 61.5% from 62.8 fatal crashes per 100,000 vehicles in Y-2000 to 24.2 in Y-2010 to meet the published DOT target.

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[23] 49 CFR Part 390.5, defines a recordable accident as "an occurrence involving a commercial motor vehicle operating on a public road which results in a fatality; bodily injury to a person who, as a result of the injury, immediately receives medical treatment away from the scene of the accident; or one or more motor vehicles incurring disabling damage as a result of the accident; requiring the vehicle to be transported away from the scene by a tow truck or other vehicle.".

[24] Insurance analyses of 24,636 heavy truck accidents in Australia from 1989-1999 undertaken by Allianz showed that the average cost for all accident claims was A$7,152, yet single vehicle loss of control accidents where driver fatigue was the major causal factor, have an average value A$104,933 (severity accidents). Loss of control accidents where driver fatigue was determined to be a factor represented 11% of all accidents over 10 years, but 34% of the total claims cost indicating that driver fatigue is correlated with accident severity (Croke, D. personal communication)

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