Research Results

Measurement and Estimation of Sleep in Railroad Worker Employees

SUMMARY

Fatigue risk management systems provide a means to plan for and manage fatigue in round-the-clock operations such as railroading. Biomathematical fatigue models predict opportunities for sleep associated with a work schedule. The accuracy of the predictions depends, in part, upon the accuracy of the sleep estimation. The purpose of this study was to validate the sleep estimation methods used in the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model as implemented in the Fatigue Avoidance Scheduling Tool (FAST). The AutoSleep algorithm incorporated in FAST estimates sleep. The results of predictions from FAST were compared with actual sleep data as recorded by four groups of railroad workers in daily logs over a 2-week period. AutoSleep underestimated sleep for all groups of day railroad workers; however, for night workers, it overestimated sleep for night dispatchers but underestimated sleep for night train and engine service employees. Overall agreement ranged from 92 percent for signalmen to 79 percent for night dispatchers. FAST also provides a measure of effectiveness for each half hour of a work period. Although the efficiency predictions based on AutoSleep estimates of sleep differed from those based on the logbook records, the two estimates did not differ substantially. These findings validate the AutoSleep algorithm as a reasonable method to estimate sleep based on work histories when applying a biomathematical fatigue model such as SAFTE.
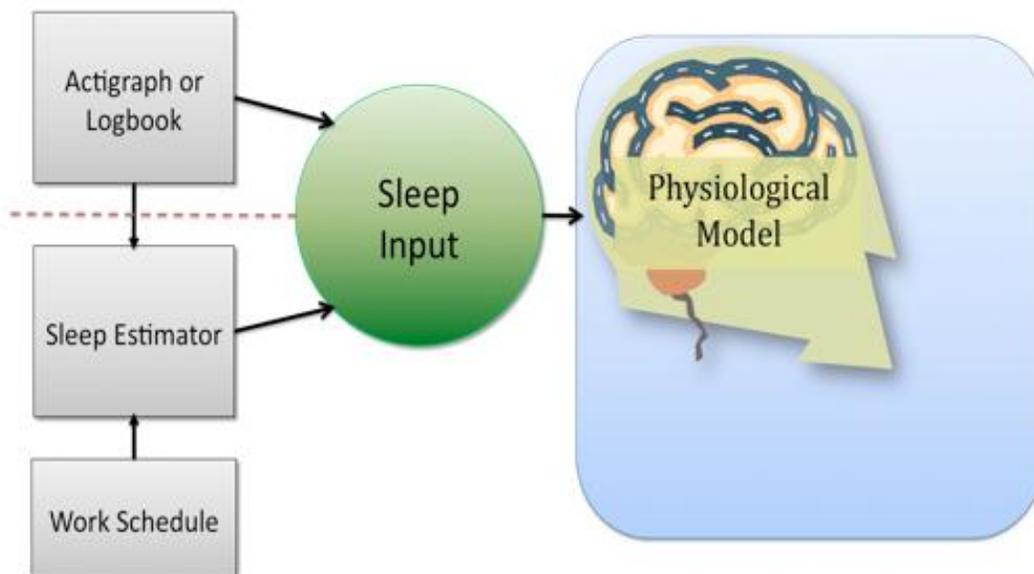
Figure 1. Fatigue Modeling Process Based on Sleep Records or Sleep Estimates

BACKGROUND

Fatigue is a constant factor in round-the-clock railroad operations. Fatigue risk management systems (FRMS) use fatigue models to assess fatigue and operational risk. Fatigue models usually estimate the amount of sleep associated with a work schedule to predict alertness or performance decrements. The accuracy of these predictions depends on the accuracy of the sleep estimations.

OBJECTIVES

The purpose of this study was to determine the accuracy of sleep estimations in the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model as implemented in Fatigue Avoidance Scheduling Tool (FAST).

METHODS

Sleep data were collected through four surveys of employees at U.S. railroads (Gertler & Viale, 2006a,b, 2007; Gertler & DiFiore, 2009). The studies used a daily log that recorded sleep, work periods, and personal time for a 2-week period. The surveys were mailed to random samples of four railroad craft groups (dispatchers, maintenance-of-way, signalmen, and train and engine (T&E) crews).

The sleep records were used to characterize the levels of sleep restriction in each work group and the expected changes in performance based on the SAFTE model (Hursh, et al., 2004; Hursh & Van Dongen, 2010). Sleep was estimated from the work schedules with the AutoSleep algorithm which is used in FAST (Hursh, Balkin, Miller, & Eddy, 2004). The study evaluated the accuracy of the AutoSleep algorithm and the resulting predictions of performance and fatigue.

Figure 1 illustrates the general approach for sleep estimation. Records of sleep can be obtained using a logbook or wrist actigraphy recordings from workers. These records can inform or validate sleep estimates based on an algorithm that simulates the sleep decisions of the workers driven by the work schedule and physiological circadian factors. This study used logbook data to validate the computer-based sleep algorithm.

To validate the FAST sleep estimates, AutoSleep used work schedule data to estimate sleep periods. The work histories for those with irregular day and night work were analyzed separately from those with at least 50 percent of work starts between 2200 and 0400 (called regular night workers). Regular night workers have a different sleep pattern than those who work irregularly during the day and night. AutoSleep has settings for the typical bedtime, the No Sleep Zone when no sleep is usually taken, and the maximum sleep expected on work days and rest days. The following settings were used for the irregular day and night workers: Bedtime 2300; No Sleep Zone 1300-1900; Rest Day Maximum Sleep 9 h; and Work Day Maximum Sleep 8 hours (h). For regular night workers, the best settings for AutoSleep were as follows: Bedtime 2300; No Sleep Zone 1600-1900; Rest Day Maximum Sleep 9 h; and Work Day Maximum Sleep 7 h.

RESULTS

Sleep Estimates

Actual and predicted sleep times were compared for each minute. A correct estimate was counted when the predicted state of a minute (wake or sleep) agreed with the logbook state and was converted to a percent of the total minutes in the record. The percent agreement and the total sleep per day error (estimate minus log) are shown in Table 1 for signalmen, maintenance-of-way, dispatchers (excluding night workers), and T&E crews.

The percent agreement for night dispatchers was 79 percent compared with 90 percent for irregular day and night dispatchers. AutoSleep overestimated sleep for night dispatchers by about 19 minutes (min) per day. For T&E workers on night schedules, agreement was 82 percent compared with 88 percent for irregular day and night T&E workers. AutoSleep underestimated sleep by about 40 min per day.
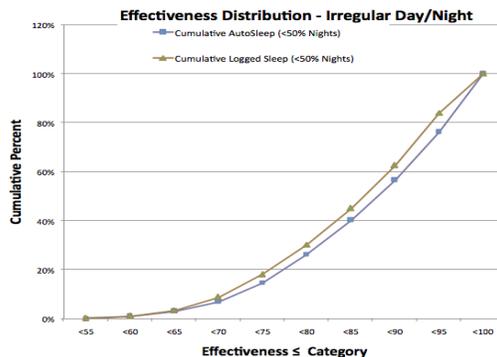

Figure 2 Cumulative Percent Work Time as a Function of Effectiveness

Table 1. Accuracy of Sleep Predictions

Irregular day and night worker

Measure	Signalman	MOW	Dispatcher	T &E
Mean Agreement	92%	92%	90%	88%
Error (Est.-Log)	-24 min	-21 min	-3 min	- 10.8 min

Regular night workers

Measure	Night Dispatchers	Night T & E
Mean Agreement	79%	82%
Error (Est.- Log)	+18.8 min	- 40.2 min

Effectiveness Based on Estimated versus Recorded Sleep

How does the error in sleep estimation affect predictions of performance effectiveness? For the T&E crews, effectiveness was predicted from logbook-recorded sleep and AutoSleep-estimated sleep. Figure 2 displays cumulative effectiveness curves for logbook measures of sleep and AutoSleep estimates of sleep. The two curves are very similar, indicating that estimates of fatigue based on sleep estimated from work histories are very close to what is obtained when fatigue scores are based on actual sleep.

These same results are shown in Figure 3 as a discrete distribution of percent of work time in each effectiveness category.   Effectiveness estimates in categories below 65 are virtually identical. Estimates based on logged sleep are slightly higher (no more than 1.7 percent) than with AutoSleep in categories from 65 to 95. In the 95-100 category, estimated work time based on AutoSleep was greater than that, according to the logbook data, perhaps because the AutoSleep algorithm tends to arrange a full night of sleep whenever the opportunity exists, whereas the logbooks indicated that subjects often do not take a full night of sleep, even when possible.

Figure 4 shows the overall correlation of effectiveness scores between estimated (AutoSleep) sleep and logbook sleep for night T&E and irregular day and night T&E. The dashed regression line for AutoSleep effectiveness versus logbook effectiveness for the
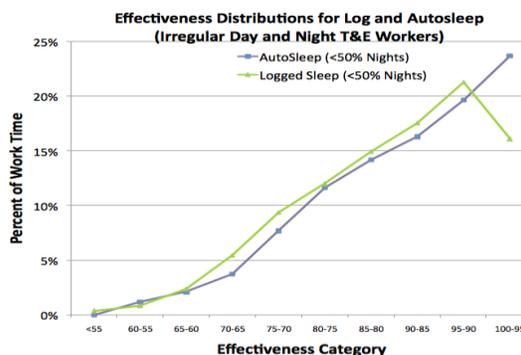

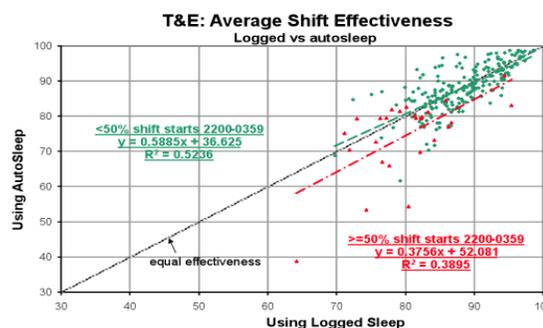**Figure 3 Percent of Work Time as a Function of Effectiveness**

Figure 4. Effectiveness Scores for AutoSleep versus Logbook Sleep

workers not working consistent night shifts was nearly identical to the major diagonal that indicates perfect agreement. The scatter of the points represents individual differences in sleep pattern under equivalent work conditions. For the consistent night workers, the estimates are consistently below what would be predicted based on logbook-recorded sleep (dotted line). Since AutoSleep tended to underestimate the actual amounts of sleep, it is not surprising that effectiveness estimates were consistently lower than what would be predicted based on logbook sleep (dotted line). Nevertheless, the slope of the line is parallel to the major diagonal, indicating equivalent sensitivity to the effects of work schedule on predicted performance using estimated sleep.

CONCLUSIONS

Comparisons between sleep times recorded in logbooks and estimates of sleep based on the FAST AutoSleep algorithm indicated 88 percent agreement or better for all railroad crafts, except for workers doing regular night work. For those workers, agreement is about 80 percent. Estimates of total sleep per day for irregular day

AutoSleep underestimated sleep on average by and night workers were also relatively close; 10.8 min per day for T&E workers and no more than 24 min per day for the other crafts. When used to predict effectiveness with the SAFTE model, estimates of percent of work time by effectiveness category for T&E workers were usually in error by no more than 1.7 percent. These findings indicate that the AutoSleep algorithm is a reasonable method to estimate sleep based on work. In combination with the previous report validating the SAFTE model for prediction of accident risk (Hursh, Raslear, Kaye, & Fanzone, 2006), these findings confirm the utility of using fatigue modeling as part of a fatigue risk management system (Van Dongen & Hursh, 2010).

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ACKNOWLEDGMENTS

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