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Antecedents of fatigue, close calls, and crashes among commercial motor-vehicle drivers☆

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Abstract

Problem: Minimizing driver fatigue among commercial motor-vehicle (CMV) drivers is a major safety issue in the United States. This study examines the effects of potentially fatigue-inducing factors inherent in truck driving work and company safety management in explaining: (a) drivers driving while fatigued, (b) the frequency of close calls due to fatigue, and (c) actual crashes among CMV drivers. *Method*: Data for this study are derived from a survey of CMV drivers in 116 trucking firms, with all data being driver-reported. The relative roles of fatigue-inducing factors and safety management practices in explaining variation in fatigue, close calls, and crashes are reported, along with the roles of fatigue in affecting close calls and crashes via hierarchical regression. *Results*: Findings indicated that fatigue-inducing factors inherent in driving work and safety practices accounted for appreciable variation in driving fatigued (R^2 = .42) and close calls (R^2 = .35), but not crash involvement. Driving while fatigued also accounted for incremental increases in the amount of variation in close calls, after consideration of inherent factors and safety practices. *Impact on industry*: Findings indicate that 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.

Keywords: Driver fatigue; Close calls; Crashes; Safety management practices; Trucking industry

Safety in the workplace has always been a topic of major interest and importance to employees, managers, unions, government policy makers, and researchers seeking to understand how best to minimize the frequency and severity of accidents. Workplace safety issues become even more important when public safety can be affected by workplace behavior. Perhaps no better example of the link between workplace behavior and public safety can be seen than in the driving behavior of over 3.6 million (Bureau of Transportation Statistics, 2002) commercial motor-vehicle (CMV) drivers (i.e., truck and motor coach operators) in the United States. The CMV driver workplace essentially consists of public streets and highways. Crashes involving large trucks, the focus of this study, result in about 5,000 deaths and 133,000 nonfatal injuries per year (Office of Motor Carriers, 1998). Moreover, the National Transportation Safety Board estimates that 31% of all truck driver fatalities and 58% of all single-truck crashes are fatigue-related (Schulz, 1998). The extent to which drivers engage in safe driving practices (including defensive driving to avoid accidents that would otherwise be caused by the driving public), and avoid becoming fatigued while driving, is thus of major importance. The purpose of this study is to identify fatigue-inducing and company safety management factors most relevant to the prediction of: (a) driving while fatigued, (b) close calls due to fatigue (i.e., "near-accidents"), and (c) actual crash involvement among CMV drivers engaged in intra- and interstate (i.e., "heavy") truck driving work.

Concern for public safety has led to a series of federal laws that govern the driving behavior of CMV drivers. Usually referred to as hours-of-service (HOS) regulations,

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these laws specify that CMV drivers may drive up to 10 hours after a mandatory 8-hour off-duty period. Current regulations also allow drivers to spend an additional five hours on duty performing non-driving tasks such as loading and unloading or paperwork. Drivers are restricted to 70 hours of driving over an 8-day period but can legally accumulate these 70 hours within five days (Federal Highway Administration, 1996b). Many drivers freely acknowledge exceeding these limits (Beilock, 1995; Braver et al., 1992; Williamson, Feyer, Coumarelos, & Jenkins, 1992) and drivers that do are more likely to be involved in accidents (Williams & Monaco, 2001). Accordingly, an underlying issue of this study is why drivers are motivated to violate HOS regulations and/or continue to drive when they are fatigued.

1. Driver fatigue, close calls, and crashes

CMV drivers realize high annual mileage exposure, often 5–10 times that of passenger vehicles (Wylie, Shultz, Miller, Mitler, & Mackie, 1996). Because of this exposure, CMV driver risk of being involved in a crash would seem to be far greater than that of non-commercial drivers. In fact, however, when adjusted for exposure, CMV drivers are *less* likely to be involved in crashes than drivers who do not drive for a living (Wylie et al.). This is likely due to the fact that professional drivers are less likely to engage in alcohol use, speeding, and other unsafe driving acts than other drivers. In addition, the bulk of their driving may be on safer, interstate and other limited-access highways. Still, governmental responsibility for establishing safety regulations for CMV drivers has inspired policy makers to hold CMV drivers to a higher standard, especially with respect to the number of hours drivers may drive and accident culpability. The most current government regulations, for example, have reduced the use of the word "accident," in favor of the term "crash" to convey the idea that these outcomes are *not* uncontrollable.

A number of factors impede research seeking to understand the relations among driver fatigue, close calls, and crashes. Crashes, fortunately, are relatively rare events typically involving multiple causal elements (i.e., factors other than CMV driver fatigue play a role). In addition, the measurement of crash outcomes is frequently marked by restriction in range, which in turn reduces detection of statistically significant findings. Proxies for crash involvement such as "near accidents" or "frequency of close calls" are thus often used in this line of research (e.g., Harris & Mackie, 1972; Williamson, Feyer, Friswell & Leslie, 1994). Moreover, reliance on proxy measures is generally accepted in safety research since the frequency of near accident occurrences is positively associated with actual workplace injuries and accidents (e.g., Hofmann & Stetzer, 1996; Zohar, 2000). Measures of close calls and driver fatigue have their own limitations. They are generally based on self-report and thus subject to recall biases, attributional errors, and under-reporting due to fear of self-incrimination. For these reasons and with these caveats in mind, the study propositions outlined below will not distinguish among the three outcome measures (i.e., driver fatigue, close calls, and crashes) separately.

2. Literature review

Theoretical models explicating the factors that might explain CMV driver accident behavior are sorely lacking, despite their practical importance. Most research has been undertaken by consulting firms, with some academic research conducted through federally sponsored research projects. The results of these investigations are frequently published in technical reports that are not widely disseminated. However, there appears to be consensus in this literature (e.g., Braver, Preusser, & Ulmer, 1999; Hanowski, Wierwille, & Dingus, 2003; Mackie & Miller, 1978; Wylie et al., 1996) that CMV driver fatigue experienced while driving is a common determinant of close calls and crashes. The role of fatigue in accidents is also likely to be underestimated, as accident reports and case testimony frequently cite contributing accident causes to be "inattention," "distracted," "daydreaming," "looked but didn't see," – all explanations that may be synonymous with or closely linked to fatigue (Evans, 1991). Driver fatigue, in turn, is thought to be the result of a wide array of factors, with some an inherent function of driving work and others more reflective of company safety practices.

2.1. Fatigue-inducing factors

A wide variety of factors that characterize truck-driving work are potential contributors to fatigue- and crash-related outcomes. Work overload, schedule irregularity, and working at a variety of times, which run counter to natural circadian rhythms are three potential contributors. Disturbance in sleep patterns, inferred from difficulties in finding a safe place to rest and achieving an adequate number of hours of continuous sleep when working, represent two more potential contributors to fatigue and crashes. Insufficient recovery from prior work that results in starting the next work period still tired is another. Lastly, the common practice of involving drivers in the loading and unloading of their cargo may contribute to undesirable consequences.

2.1.1. Work overload

Estimating the extent to which drivers are likely to experience work overload because of excessive driving during some time frame is difficult because the actual number of hours driven by truck drivers frequently exceed the legal limits, and driver logbooks are notoriously unreliable (Braver et al., 1999). One study determined 73% of all truck drivers to be HOS violators (Braver et al., 1992). The average number of miles driven per week is a good substitute for work hours as drivers are frequently paid on a per mile basis, and thus miles are less likely to be underreported. Drivers who drive more miles are more likely to violate HOS regulations, drive when drowsy (McCartt, Wright, Rohrbaugh, & Hammer, 2000), and be involved in crashes (Williams & Monaco, 2001). A large number of investigations have demonstrated that long driving hours increase fatigue and crash risk (e.g., Kaneko & Jovanis, 1992; Lin, Jovanis, & Yang, 1994; Raggatt, 1991), independent of the effects of nighttime driving (Lin et al., 1994; Saccomanno, Shortreed, & Yu, 1996). More broadly, Hofmann and Stetzer (1996) found that role overload (i.e., excessive work demands relative to time allotted) was significantly associated with unsafe behaviors in plant-based settings. Accordingly, we expect to see a positive association between the average number of miles driven per week and the outcome measures.

2.1.2. Schedule regularity and number of time blocks

While some truck drivers are assigned to runs that allow them the luxury of starting and stopping at the same time each day, most drivers (i.e., the long haul, over the road truckers), experience irregular driving times and are required to drive around the clock in order to deliver their freight in a timely fashion. Their work takes on the characteristics of rotating shift work combined with potential sleep deficit problems that emerge with constant changes in work and rest times. It is not uncommon for drivers to drive mornings, afternoons, evenings, and between midnight and 6 a.m. in the course of a normal run. Driving patterns that run counter to circadian rhythms have been shown to result in falling asleep while driving and crashes (Horne & Reyner, 1999). Irregular driving schedules have also been linked to violations of hours of service regulations and fatigue (Braver et al., 1992). Therefore we anticipate that drivers with more schedule regularity will experience less fatigue while driving and fewer close calls and crashes. Drivers who drive at more diverse times around the clock are expected to report more undesirable outcomes.

2.1.3. Disturbances in sleep patterns

The scheduling requirements of CMV driving work just mentioned often result in truck drivers getting inadequate and poor quality daily sleep. Such deficits, in turn, have been found to adversely affect driving performance (Balkin et al., 2000). Wylie et al. (1996) report that CMV drivers average 4.8 hours of sleep during their principal sleep periods, far less than is necessary as judged by formal clinical criteria. In addition, Williams and Monaco (2001) found an inverse relationship between the number of hours slept in the past 24 and the frequency of violating HOS regulations (i.e., driving when fatigued). The lack of sleep situation is further aggravated by the lack of safe rest places for truck drivers (Federal Highway Administration, 1996a). Drivers may be forced to continue to drive when no rest options are readily available. Accordingly, we hypothesize that difficulty in finding a place to rest will be positively related to undesirable driving outcomes while the average number of hours of sleep in a 24-hour period when working should be negatively related to these outcomes.

2.1.4. Insufficient recovery

While HOS regulations prescribe minimal rest requirements for CMV drivers, little attention has been rendered to how recovery (i.e., rest or non-duty) time is used. Recovery involves psychological as well as physiological readjustment following a work period. Totterdell, Spelten, Smith, Barton, and Folkard (1995) point out that little is known about the cumulative effects of consecutive work periods and how recovery takes place over rest periods. They assert that working at night and variable work schedules, both common in truck driving work, likely exacerbate the length of time recovery takes. For driving employees, there is also the issue of returning home and trying to adjust to family schedules, engage in domestic activities, and so forth during the scheduled time off. The effective use of free time for rest may be curtailed under these circumstances (Colligan & Rosa, 1990). Accordingly, we propose that insufficient recovery, regardless of whether it is due to inadequate time or use of time, should be positively associated with fatigue, close calls, and crashes.

2.1.5. Nature of trucking work

The trucking industry is exceedingly time sensitive with many drivers recognizing that when they are not moving, they and their firms are not making money. Thus, there are strong economic pressures to minimize the time devoted to loading and unloading trucks by shippers and receivers. Drivers have an incentive to help with these activities if it gets them back on the road more quickly. The effects of driver participation in loading and unloading activities are mixed. These activities initially improve alertness by providing diversion and exercise; however, these effects wear off quickly and result in decreased driving performance after 12 hours of duty (O'Neill, Krueger, Van Hemel, McGowan, & Rogers, 1999).

Accordingly, we hypothesize that the percent of time spent in loading activities will be positively associated with study outcome measures.

The collective impact of these factors common in truck driving work suggests a single overarching proposition:

P1. *Fatigue-inducing factors in truck driving work account for variation in (a) fatigue while driving, (b) the frequency of close calls due to fatigue, and (c) crash involvement.*

2.2. Company safety management practices

A growing body of research has begun to document the role management practices can have in getting workers to work more safely (Hofmann, Jacobs & Landy, 1995;

Parker, Axtell, & Turner, 2001). Development of strong safety climate perceptions among employees (i.e., policies, procedures, and practices supportive of occupational safety) and institution of safety supportive policies are frequently mentioned. In the trucking industry, the latter might include practices such as limiting unsafe driver behavior like driving at night, minimizing fatigue-inducing behaviors like loading and unloading, and not allowing dispatchers to pressure drivers to continue driving when drivers report being tired.

While there is a rather expansive literature *advocating* a linkage between safety climate and various types of industrial accidents, only very recent studies have empirically substantiated a link between safety climate and: (a) accidents (Barling, Loughlin, & Kelloway, 2002; Gillen, Blatz, Gassel, Kirsch, & Vaccaro, 2002; Zohar, 2000); and (b) unsafe work behaviors (Griffin & Neal, 2000; Hofmann & Stetzer, 1996). Building on these investigations, the present study hypothesizes that driver perceptions of strong management commitment to safety and driver involvement in safety activities is associated with less willingness to drive when fatigued, close calls, and crash involvement.

Supportive safety policies, for this study, are limited to those company practices that have a bearing on driving fatigue and safety. In trucking organizations, there is controversy as to whether drivers should be permitted to drive at night, especially between midnight and 6 a.m., when crashes are more frequent (Häkkänen & Summala, 2001) and more severe (Blower & Campbell, 1998). Companies with policies that encourage drivers to avoid driving and sleep during these hours (i.e., sleep patterns that are more consistent with normal circadian rhythms) should, logically, see lower reports of driving while fatigued. Similarly, companies that minimize loading/unloading by drivers (e.g., through providing financial resources to hire loading help, requiring shippers and receivers to handle this burden), should see comparable results as driving skills deteriorate as the work period lengthens (O'Neill et al., 1999). The extent to which dispatchers pressure drivers to continue driving when they are tired is the last company practice to be considered. According to surveys of dispatchers, revenue generation is the primary determinant of whether or not to accept or reject a load (Braver et al., 1999). Depending on company policy, dispatchers may be motivated to accept high revenue loads even when drivers are unlikely to be able to deliver loads on time and within rest requirements. Accordingly, some dispatchers may be motivated to pressure drivers to continue driving in order to enhance their job performance, and thereby increase the probability of drivers continuing to drive when fatigued. Moreover, to the extent that dispatchers function as drivers' supervisors, literature on supportive supervision and safe working (e.g., Hofmann & Morgeson, 1999; Parker et al., 2001) would predict that dispatcher pressure to drive would adversely affect the outcome variables.

Since all three of the policies reflect the level of job autonomy afforded drivers, and autonomy, in turn, has been associated with a number of safety outcomes in a variety of work settings (Parker et al., 2001), we hypothesize that companies with policies minimizing nighttime driving and loading activity should have drivers reporting less fatigue and fewer close calls and crashes. In contrast, pressure from dispatchers to continue driving is hypothesized to have the reverse effect.

Accordingly, we propose that company safety management practices can affect fatigue related outcomes after consideration of fatigue-inducing factors endemic to truck driving work:

P2. *After controlling for fatigue-inducing factors, company safety management practices account for variation in: (a) fatigue while driving, (b) the frequency of close calls due to fatigue, and (c) crash involvement.*

Lastly, the role of driving while fatigued in predicting close calls due to fatigue and crashes is examined. We expect that driving while fatigued will function as an independent predictor of close calls and crash involvement.

P3. *After controlling for fatigue-inducing factors and company safety management practices, fatigue while driving accounts for variation in: (a) the frequency of close calls due to fatigue, and (b) crash involvement.*

3. Method

3.1. Sample and data collection

Data for this study are drawn from a larger study of motor carrier scheduling practices in U.S. trucking concerns (Crum, Morrow, & Daecher, 2001). Briefly, in order to be eligible to participate in the study, firms had to be included in the federal government's Office of Motor Carriers Census file and the Motor Carrier Safety Status Measurement System database known as SafeStat. There were 77,216 firms exclusively engaged in trucking in 1999 and thus eligible for selection. The population was then further restricted to firms with at least four drivers, leaving 21,292 carriers to be sampled.

Using the safety performance data included in SafeStat, and in an effort to realize the full range of variation in safety performance and practices, these companies were grouped into three safety performance rating categories (poor, average, and top safety performers). Sample carriers were randomly selected from within each category. Of the companies that were contacted by telephone to solicit their participation (566), 66.1% agreed to participate (374). Of these firms, 116 (20.5%) returned usable surveys, with 32 from top safety-performing firms, 53 from average firms, and 31 from poor performing firms. Not quite half (47.3%) of these carriers were "for-hire" companies while 52.76%

described themselves as private carriers (companies hauling their own products).

The data collection methodology called for the safety director at each firm to distribute a survey to three "typical" drivers. Each respondent was instructed to put her/his completed survey into the provided envelope, seal it, and return it to the safety director who would return the entire packet to the researchers. At least one driver provided usable data from each of the 116 participating firms and when more than one driver survey was returned, a single survey was randomly selected for inclusion in this study.

Drivers were overwhelmingly male (96%), ranging in age from 22 to 63 years, with an average age of 43. The average driver had 14.92 years of driving experience. Most drivers (87.6%) classified themselves as company drivers while 10.6% were owner-operators or independent contractors. Only 1.8% were temporary, casual, or leased drivers. Finally, with respect to crash behavior, 80.4% reported they had not had a "reportable to the company" crash in the past two years and 96.6% reported they had not had a chargeable crash (i.e., received a citation) during the same period.

3.2. Measures

Virtually no established measures of driver behavior or fatigue are available. While single-item measures are commonly used in transportation studies, psychometric data are seldom reported. Most of the measures employed here were expressly designed for this study based on qualitative information derived from industry experts described in Crum et al. (2001). Means, standard deviations, and intercorrelations are presented in Table 1.

3.2.1. Fatigue-inducing factors

Workload was measured by asking drivers to estimate the average number of miles driven per week over the past two years. Estimates ranged from 20 to 3,500 miles, with a mean of 1,890 miles. Schedule regularity was determined by asking drivers how often they were able to start and stop driving at nearly the same time each day. Most drivers (74%, scored "2") surprisingly reported that they usually were able to do this, with just over a quarter (26%, scored "1") of the drivers indicating that they were not. The number of 6-hour time blocks driven in the course of a day was measured by asking drivers to specify the time blocks they normally spent more than 10% of their driving time: 6 a.m. to noon, noon to 6 p.m., 6 p.m. to midnight, and midnight to 6 a.m. The number of time blocks was summed. Just over half the drivers (50.9%) were able to limit their time blocks to two, 27.6% reported three time blocks, and 21.6% reported that they commonly worked during all four time blocks. Difficulty in finding a place to rest was operationalized by asking drivers whether they had difficulty in finding a safe place to rest or sleep. Nearly two-thirds (63.7%) said this was not a problem while 35.7% indicated that this was a concern. Adequacy of sleep when working was determined by classifying the drivers who reported sleeping an average of five hours or less into a " less than adequate" (based on Wylie et al., 1996) sleep group and classifying those drivers reporting more than five hours of sleep as an "adequate" sleep group. Forty–two (36.2%) of the drivers were judged to receive inadequate sleep while 74 (63.8%) received adequate sleep. Insufficient recovery was gauged by asking drivers how frequently they began a new "workweek" feeling tired or fatigued. Just over half (53%) said this never or only rarely happened to them (scored "1") while 47% indicated that this happened with greater frequency (scored "2"). Estimates of the percent of work time drivers engage in loading or unloading cargo were provided by drivers. These estimates ranged from none of the time (8.6%) to 70% of the time (0.9%), indicating that nearly all drivers must do some loading or unloading in the course of their work.

3.2.2. Company practices

The perceived safety climate employed was developed for this study following a determination that Zohar's (1980)

Table 1
Means, standard deviations and correlations among study variables

Variable	Means	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Work overload (Avg. miles/week)	1890.42	891.33														
2. Schedule regularity	1.74	.44	− .29													
3. # 6-hr time blocks	2.68	.84	.40	− .17												
4. Difficulty finding rest places	1.36	.48	.36	− .16	.20											
5. Adequacy of sleep	1.64	.48	.03	.06	.23	− .05										
6. Insufficient recovery	1.47	.50	.10	.04	.14	.12	− .08									
7. % time loading	17.34	14.63	− .43	− .05	− .17	− .16	− .02	− .08								
8. Safety climate	56.45	15.54	.05	.06	.02	− .15	.18	− .17	− .01	(.94)						
9. Minimize nighttime driving	.26	.44	− .14	.18	− .17	− .13	.23	− .01	.14	.00						
10. Minimize loading/unloading	.42	.50	.20	− .02	.03	.08	.31	− .04	− .16	.10	.11					
11. Pressure to drive tired	2.38	1.84	− .01	.06	.12	.10	− .19	.23	− .13	− .58	− .08	− .21				
12. Fatigue while driving	6.03	2.30	.19	.00	.14	.23	− .18	.50	− .26	− .43	− .19	− .16	.44	(.74)		
13. Close calls	12.18	4.19	.23	.08	.26	.24	.09	.23	− .10	− .26	.12	− .14	.28	.39	(.80)	
14. Crash involvement	.22	.71	− .12	.09	− .03	− .12	− .07	− .05	.24	− .18	− .01	− .07	.10	.08	.10	(.85)

Note: Correlations $\geq \pm .19$ are statistically significant at $p \leq .05$ (two-tailed). Correlations $\geq \pm .26$ are statistically significant at $p \leq .01$ (two-tailed). Alpha reliability estimates are in parentheses along the diagonal.

more established scale was not appropriate for this sample (e.g., it included a scale item that refers to fellow workers reactions to safety violations, which is not appropriate given the low task interdependence of truck driving work). Drawing on a review of the trucking literature, industry focus groups, and site visits to 13 carrier sites (Crum et al., 2001), 11 perceived safety climate items were formulated. These items consisted of statements posed to drivers regarding driving safety (e.g., "Our Company makes driving safety a top priority" and "This Company is interested in driver input on driving safety matters). Drivers recorded their level of agreement using a 1 (to a very little extent) to 7 (to a very large extent) response framework. Factor analysis supported a single factor structure and the Cronbach α was .94. Scores ranged from 15 to 77 with a mean of 56.45. The extent to which drivers perceive that their companies minimize driving at night was determined by asking drivers whether or not their company actually did this, with no responses coded "0" and yes responses coded "1". Seventy-four percent responded "no." The extent to which drivers perceive that their companies minimize loading and unloading by drivers was evaluated in the same manner. Over half (57.7%) responded that their company did not minimize loading and unloading. Drivers' views on the extent to which dispatchers pressure drivers to continue driving when drivers are tired was operationalized by asking drivers the extent to which they agreed with this statement using a response framework from 1 (to a very little extent) to 7 (to a very large extent). As reflected in the mean of 2.38, this was not a pervasive problem, though actual responses ranged from 1 to 7.

3.2.3. Fatigue related measures

The use of self-report measures of fatigue has been shown to be superior to other measurement approaches (e.g., automatic sleep detectors). Drivers have been shown to be aware of precursory states of increasing tiredness, further supporting the use of self-reports (Horne & Reyner, 1999). Accordingly, a 3-item measure of the frequency with which drivers reported they: (a) nod off while driving, (b) think fatigue is a problem for them while they are driving, and (c) find themselves continuing to drive when they are less than fully alert was devised. Response options for each item ranged from 1 (never) to 5 (very frequently). The responses were summed, supported by a single factor structure, and yielded a Cronbach α of .74. The frequency of close calls was assessed using a summated 6-item measure. Drivers were asked how often they had had a close call because they were less than fully alert at six sites: (a) terminals, (b) weigh stations, (c) truck stops, (d) shipper/receiver facilities, (e) while driving in urban areas or on secondary roads, and (f) while driving on interstates. The response framework for each site was again 1 (never) to 5 (very frequently). A single factor structure was observed and a Cronbach α of .80. Lastly, crash involvement was measured using the sum of two items. Drivers were asked how many: (a) reportable (to the company), and (b) chargeable accidents they had been involved in while working

Table 2
Results of hierarchical regression analysis predicting fatigue, close calls, and crash involvement of truck drivers

Step and Predictor	Model 1: Fatigue While Driving		Model 2: Frequency of Close Calls			Model 3: Crash Involvement		
	Step 1	Step 2	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
Step 1: Fatigue-inducing Factors								
Work overload-avg. miles/week	.10	.20†	.10	.18	.14	.00	.04	.00
Schedule regularity	.03	.04	.23*	.20*	.20*	.16	.17	.17
# 6-hour time blocks	.04	− .02	.13	.13	.13	.09	.09	.10
Difficulty finding rest places	.11	.05	.23*	.20*	.18†	− .09	− .14	− .14
Adequacy of sleep	− .14	.03	− .01	.07	.07	− .08	− .05	− .05
Insufficient recovery	.41***	.32***	.28**	.19*	.08	− .05	− .10	− .14
% time loading	− .14	− .10	.09	.07	.11	.26*	.27*	.30*
Step 2: Company Safety Management Practices								
Safety climate		− .25**		− .14	− .05		− .20	− .16
Minimize nighttime driving		− .10		.26**	.30***		− .05	− .04
Minimize loading/unloading		− .15†		− .22*	− .18†		.03	.06
Pressure to drive		.22*		.20†	.13		.05	.01
Step 3: Fatigue								
Fatigue while driving					.34**			.17
F	5.34***	6.93***	3.58**	5.14***	5.86***	1.35	1.30	1.31
Change in F		7.06***		6.20***	8.20**		1.19	1.37
Change in R^2	.31	.18	.24	.19	.06	.10	.05	.02
Adjusted R^2	.25	.42	.18	.35	.41	.03	.04	.04

*$p < .05$.
**$p < .01$.
***$p < .001$.
† $p < .10$.

over the last two years. Thus this measure includes all crashes, and not just those attributable to fatigue. Just under a fifth (19.6%) of the drivers reported having one or more reportable accidents, while 4.4% acknowledged one or more chargeable accidents. These raw data were then adjusted to account for exposure by dividing the number of crashes by the average number of miles driven, and expressed on a per 100,000 miles basis. The adjusted distribution was essentially equivalent to the unadjusted distribution. Drivers with reportable accidents had between .32 to 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 α of .85.

3.3. Analyses

Hierarchical regression analysis was used to evaluate the study propositions. Three dependent variables are examined, drivers' Experience of Fatigue While Driving—Model 1 (which later functions as an independent variable relative to the remaining dependent variables), the drivers' Frequency of Close Calls Due to Fatigue—Model 2, and drivers' Crash Involvement—Model 3 (see Table 2). The effects of the variables representing fatigue-inducing factors were entered as Step 1 of each equation followed by the company safety practices relevant to fatigue in Step 2. Entering the company practices in a subsequent step to the fatigue-inducing factors allows examination of the unique, if any, contribution made by the company practice factors in explaining variance in the dependent variables. For Models 2 and 3, drivers' experience of fatigue while driving is entered as the final third step.

4. Results

As shown in Table 1, nearly all of the study variables exhibited reasonable variability relative to their range. Only the crash involvement measure, with no theoretical upper bound, was marked by restriction in range. Intercorrelations among the fatigue-inducing factors (r = −.02 to −.43) were sufficiently low to support independence as were those evident among the company practices (r = .00 to −.58), although the r of −.58 between safety climate and pressure to drive tired exhibited borderline multicollinearity. The dependent variables were also independent, with correlations ranging from .08 to .39. The results of the hierarchical regression analyses are presented in Table 2.

4.1. Proposition 1

Proposition 1 specified that fatigue-inducing factors would account for variation in fatigue while driving, close calls due to fatigue, and crash involvement. Step 1 of each model in Table 2 addresses this proposition. Fatigue-inducing factors explained a significant amount of variation (F = 5.34, R^2 = .25, $p < .001$) in fatigue while driving (Model 1), with insufficient recovery (β = .41, $p < .001$) accounting for most of the explained variation. Similar results (F = 3.58, R^2 = .18, $p < .01$), were observed with respect to frequency of close calls due to fatigue (Step 1, Model 2). As in Model 1, insufficient recovery appeared to be the pivotal fatigue-inducing factor in predicting the frequency of close calls (β = .28, $p < .01$). Schedule regularity (β = .23, $p < .05$) and difficulty finding a place to rest (β = .23, $p < .05$) also appeared to be instrumental, although the influence of schedule regularity was not in the posited direction. Turning to the prediction of crash involvement (Model 3), the overall amount of explained variation was nonsignificant and only one of the fatigue-inducing variables was significant. The percent of time spent loading (e.g., β = .26, $p < .05$, step 1) projected a strong and pervasive finding that remained statistically significant in each succeeding step (i.e., β = .27, $p < .05$, step 2 and β = .30, $p < .05$, step 3). It would appear that despite the controversy as to whether loading activity might increase alertness through the exercise and diversion it provides, whatever gains in alertness that might initially be realized are offset by greater crash frequency.

These findings lend partial support to Proposition 1. Fatigue-inducing factors, especially insufficient recovery, appear to play a role in determining whether a driver experiences fatigue and close calls due to fatigue. The amount of time spent loading and unloading trucks appears to have a bearing on crash involvement, though the overall role of fatigue-inducing factors was not predictive of crash involvement.

4.2. Proposition 2

Proposition 2 contended that company safety management practices should account for variation in the outcome measures, controlling for fatigue-inducing factors associated with truck driving work. The consideration of company practices added significantly to the amount of explained variation in fatigue while driving (ΔF = 7.06, ΔR^2 = .18, $p < .001$; Model 1) and frequency of close calls (ΔF = 6.20, ΔR^2 = .19, $p < .001$; Model 2), but did not add to the variation accounted for in crash involvement (ΔF = 1.19, ΔR^2 = .05, *ns*). The perception of a weak safety climate (β = −.25, $p < .01$), and higher perceptions of pressure from dispatchers to continue driving when tired (β = .22, $p < .05$) were associated with greater frequency of experiencing fatigue while driving. These factors diminished but did not render inconsequential the role of insufficient recovery (β = .32, $p < .001$) in explaining fatigue while driving. The joint ability of fatigue-inducing factors and safety practices accounted for 42% ($p < .001$; Model 1) of the variation in fatigue while driving.

The role of specific management practices to account for the frequency with which drivers experience close calls when driving due to fatigue was instructive. Policies to minimize nighttime driving (β = .26, $p < .01$) and policies to minimize loading and unloading ($\beta = -.22$, $p < .05$) were both related to close calls. Contrary to expectations, policies to minimize driving at night appeared to increase the frequency of close calls due to fatigue. However, it should be noted that policies to minimize nighttime driving were negatively related (albeit non-significantly) to fatigue while driving ($\beta = -.10$, *ns*; Model 1), leaving the utility of this practice open to further debate. The inclusion of safety practices into the model did not appear to influence the role of fatigue-inducing factors. Schedule regularity, difficulty in finding a place to rest, and insufficient recovery remained statistically significant contributors to the model.

Like Proposition 1, Proposition 2 received support with respect to fatigue while driving and close calls due to fatigue, but not in the case of crash involvement. Interestingly however, the specific practices that affected each outcome differed, with safety climate and pressure to drive affecting fatigue while driving and policies related to nighttime driving and loading/unloading related to close calls.

4.3. Proposition 3

Proposition 3 asserted 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. As shown in Step 3 of Models 2 and 3, fatigue-inducing factors, company practices and fatigue while driving predicted close calls ($\Delta F = 8.20$, $\Delta R^2 = .06$, $p < .01$), with the final model accounting for 41% of the variation ($F = 5.86$, $p < .001$), while the predictors were unsuccessful in explaining variation in crash involvement ($F = 1.31$, *ns*). While it seems logical that fatigue ($\beta = .34$, $p < .01$) should be a proximal antecedent of close calls, it is noteworthy that this role was sustained after consideration of the fatigue-inducing factors and safety practices. With further respect to close calls, the incorporation of fatigue into the model did not materially alter two previously observed relations (i.e., relations between close calls and schedule regularity ($\beta = .20$, $p < .05$) and policies to minimize driving at night ($\beta = .30$, $p < .001$) remained nearly the same). The introduction of fatigue while driving in Step 3 diminished the role of difficulty of finding a place to rest ($\beta = .18$, $p < .10$), insufficient recovery ($\beta = .08$, *ns*), and policies to minimize loading/unloading ($\beta = -.18$, $p < .10$). We conclude that Proposition 3 was supported in the case of close calls but not in the case of crash involvement.

5. Discussion

The propositions empirically examined here represent an initial attempt to identify the key elements predictive of driver fatigue, and subsequently, close calls, and crashes. The models tested herein were able to account for modest amounts, around 40%, of the variation in fatigue and close calls due to fatigue, but were unsuccessful in explaining crash involvement. While close calls (“near accidents”) are often used as proxies for crashes, these findings indicate that each outcome has unique antecedents and thus may require different explanations (e.g., percent of time spent loading was observed to be a good predictor of crashes but not related to fatigue or close calls). Perhaps the most useful contribution of this research is the finding that company safety management practices do have a bearing on safety outcomes. This provides some indication that effective management interventions may be successful in reducing driver fatigue, close calls, and crashes, even though drivers work away from close physical supervision.

Some specific findings merit comment because of their various implications for other lines of safety research. Two such lines, occupational health and organizational social exchange theory, are selected for comment here. First, both the effort-recovery and conservation of resources theories of health and well-being stress the importance of recovery and unwinding processes (i.e., insufficient recovery) to subsequent job performance (Sonnentag, 2001). The assumption has been that employees will use off-duty time to engage in restorative activities. The insufficient recovery results reported here, and qualitative information (Crum et al., 2001), indicate that drivers do not necessarily spend their nonwork time in this manner. In other words, 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. However, the results also 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). In other words, organizations can respond in ways to offset inherent fatigue in work. The perspective that firms can intervene in ways to mitigate undesirable aspects of work is consistent with current theorizing on well-being in the workplace (e.g., Danna & Griffin, 1999).

Second, the findings also suggest that the application of various social exchange theory models (e.g., psychological contracts, leader-member exchange, perceived organizational support; Blau, 1964) may enhance understanding of safety-related organizational behavior. Hofmann and Morgeson (1999), along with Barling et al. (2002), have demonstrated that the quality of leader-member exchange is significantly related to safety-related communication, commitment, and occupational injuries. This study suggests that drivers respond to pressure from dispatchers (akin to supervisors in this setting) to continue driving, as evidenced by their willingness to continue driving when they are aware of their own tiredness and experience close calls. Dispatchers may also play a role in scheduling drivers in ways that adversely affect their recovery. The exchange relationship between a driver and the dispatcher is thus a very real and practical, although not well understood, influence on driver behavior. Improved understanding of driver/dispatcher relations might constitute an under-appreciated strategy for reducing close calls and crashes.

This study also raises the question as to what factors are truly inherent in truck driving work and which are subject to management and/or government intervention. Percent of time spent loading or unloading is a good example. For most drivers, it is presently an inherent aspect of the job since drivers will often volunteer to assist in loading operations in order to get back on the road and resume earning income as quickly as possible. Moreover, delays in loading and unloading can be an independent source of stress (or anger) to drivers and consequently result in less safe driving behavior. More company involvement or government mandates to reduce driver participation in loading, categorized here as a safety practice, might well serve to reduce close calls and crashes, whether due to fatigue or stress. Other factors that should be included in future studies include driver compensation alternatives (drivers are typically paid by the mile as opposed to the hour or load) and shipper/receiver demands. Finally, future research should consider the possibility of interactions among key factors. Other investigations, for example, have demonstrated that work overload is positively related to poor quality of sleep (Raggatt, 1991). Rather than regard work overload and sleep deficits as independent of one another, their interconnection merits investigation. The relatively small sample precluded examination of interactions in the present study.

Lastly, it is apparent that some of the relations posited on the basis of prior studies did not receive empirical support or were found to be significant in the opposite direction of that posited (e.g., schedule regularity, minimizing nighttime driving). The positive association between scheduling regularity and close calls may be a sampling anomaly. An unusually high proportion of drivers (74%) in this sample reported being able to start and stop at the same time each day, suggesting they may have shorter routes and more frequent stops, which normally entail higher traffic volume and more close calls. A check on the average number of stops for pickups or deliveries of 5.12 per day supports this interpretation. A positive relation between minimizing nighttime driving and close calls might be explained by a closer consideration of how fatigue management policies can be compromised by operational practices at lower levels (Arnold & Hartley, 2001). Workplace and personal contingencies (e.g., financial rewards to drivers and dispatchers for on-time deliveries, driver desire to get home more quickly) may be perceived to outweigh the risk of nighttime driving. Stated differently, drivers may voluntarily disregard such policies even when they exist and elect to drive at night despite awareness of their greater risk exposure. Drivers mistakenly may also think that driving at night is less risky because of decreased passenger vehicle volume. A practical implication is that safety policies, incentives, and perceptions of risk must be examined at the individual (i.e., driver) level and that potential offsetting behavioral inducements must be considered. More generally speaking, safety policies and interventions seeking to influence individual decisions to engage in unsafe behavior and curb accidents should always be considered from individual and organizational levels (Hofmann & Stetzer, 1996).

5.1. Limitations

The primary limitations of this research involve potential sampling bias (e.g., low percentage of firms agreeing to participate in the project, safety director selection of drivers), the use of measures without established validity, and reliance on single item measures for the independent variables. The reliance on driver self-report, which makes the research open to the criticism that all data have originated from a single source (i.e., a common method variance problem) and thus relations may be over-estimated, is another limitation that will be difficult to overcome in future studies. However, it is the only practical means of operationalizing some of the independent variables, such as fatigue while driving and close calls due to fatigue. Still, future research should seek more creative ways to overcome this problem, perhaps through driver work diaries for such factors as schedule regularity, time blocks, sleep behavior, and recovery experiences. Obtaining driver cooperation, however, will not be easy as the lack of accuracy associated with written driver logbooks has repeatedly shown (Braver et al., 1999). Company records might provide more accurate data on some variables such as miles driven and driver loading time involvement.

Another possible limitation is the restriction in range associated with the self-report crash involvement measure. Highly skewed distributions typify accident measures since they have low base rates (Hofmann & Stetzer, 1996; Zohar, 2000) and were thus one of the reasons for inclusion of the close calls measure in this study. However, self-incrimination and social desirability effects would be biased in the direction of under-reporting, and thus serve to attenuate the relationships reported (i.e., be conservative in the face of common method variance criticisms). In addition, the crash measure is flawed (for the purposes of this study) by its inclusion of all crashes, not just those emanating from fatigue. Lastly, inferences about fatigue and safety that can be drawn from this study are necessarily limited to the truck driving population. While the unique nature of truck driving work impedes generalizability, we assert that the over 3 million people employed as truck drivers in 1999 (Bureau of Transportation Statistics, 2002) are a meaningful group in their own right. Moreover, truck driving work is an ideal occupation for future studies of safety, fatigue, and stress. Truck driving is a high demand (in terms of attention and decision-making requirements) but low control (i.e., monotonous, subject to external demands of company, customers, and driving environment) occupation, characteristics with demonstrated linkages to poor individual health and well being (Danna & Griffin, 1999). In addition, the stress associated with trucking work is likely to continue to escalate as economic pressures on motor carriers continue to increase and shippers demand increasingly more precise delivery times (Braver et al., 1999). The practical importance of reducing injuries and death among this group and the driving public speaks for itself.

6. Conclusion

Highway fatalities remain the leading cause of job-related deaths (Danna & Griffin, 1999) and yet academic interest in understanding this important topic is low and fragmented across disciplines. As Zohar (2000, p. 587) recently asserted, "...despite the importance of safety issues, they have been largely disregarded by students of management and organizational behavior." Barling et al. (2002) echo this assessment by reporting that less than 1% of organizational research published in top journals focuses on organizational safety. Various representatives of the motor carrier industry and highway safety interest groups have jointly agreed that driver fatigue is the most important public policy transportation issue (U.S. Department of Transportation, 1995). Hence, the lack of inquiry is not readily explicable. It is hoped that the scientific community will join forces to build upon the preliminary research presented here in the hope of one-day identifying all of the true causes of driver fatigue, close calls, and crashes and the appropriate interventions to reduce their frequency.

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