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Truck Driving Environments and Their Influence on Driver Fatigue and Crash Rates

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The development of a typology of commercial vehicle driving environments, estimate of the percentage of drivers falling into each type of driving environment, and driving environment effects on driver fatigue are described. A model of commercial motor vehicle driver fatigue, based on literature sources and focus groups of industry professionals, is proposed. Three driving-environment factors (regularity of time, trip control, and quality of rest), comprising 25 indicators, are included in the model. Data were collected via a nationwide survey of 502 randomly selected over-the-road commercial truck drivers. Data analysis revealed 12 driving-environment indicators to be good predictors of fatigue and crash outcomes. Various 2 × 2 × 2 driving-environment typologies were created by using different high-low combinations of these 12 indicators. A typology based on the single best predictors of fatigue and crash outcomes from each driving-environment factor was selected for examination (i.e., favorable and unfavorable combinations of driving the same hours, waiting longer than expected for loads, and starting the workweek tired). The percentage of drivers working in each type of driving environment ranged from 5.2 percent to 20.1 percent. Additionally, the typology was significantly related to frequency of close calls and perceptions of fatigue. The 12 driving-environment indicators collectively accounted for 5 percent and 23 percent of the variability in close calls and fatigue perceptions, respectively ($p \leq .001$), and 2 percent of the variability in crash involvement ($p \leq .07$). Implications for fatigue management are also discussed.

The work environment of over-the-road commercial truck drivers as it relates to fatigue is of particular interest to policy makers and motor carriers. Described here are the development of a typology of driving environments, an estimate of the percentage of commercial vehicle drivers falling into each type of driving environment, and how the driving environment influences driver fatigue. Because of anticipated changes in the current hours-of-service regulations, the study was conducted in a regulation neutral approach.

RESEARCH METHODOLOGY

The research methodology used in this project was described in detail by Crum et al. (*1*). First, an extensive literature search yielded 55 studies directly focused on driver fatigue. Second, the research team conducted four focus groups made up of carrier personnel involved in driver scheduling (i.e., drivers, dispatchers, safety directors, and top management) and interviewed industry professionals at 13 carrier firm and private fleet sites. The industry professionals confirmed the findings from the literature review and provided insights that aided the development of a survey instrument.

Information from the literature and industry experts was used to develop the conceptual model of commercial motor vehicle (CMV) driver fatigue depicted in Figure 1, one component of which is the driving environment. On the basis of this model, a survey instrument was developed to collect data that would enable development of a typology of truck driving environments and determination of how driving environments are related to safety performance and driver fatigue.

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CMV Driver Fatigue Model

Three general categories of fatigue antecedent, or factors that are hypothesized to affect driver fatigue, emerged from the literature review and are included in the CMV driver fatigue model: CMV driving environments, economic pressures, and support for driving safety. CMV driving environments and economic pressures are hypothesized to exert a direct influence on driver fatigue, and each of these factors, in turn, comprises three constructs. Carrier support for driving safety is a driver fatigue moderating factor and a stand-alone construct.

Driving Environments

The three hypothesized constructs making up CMV driving environments are regularity of time, quality of rest, and trip control. In total, the model proposes 25 individual measures or indicators within these constructs.

Regularity of time is concerned with the opportunity for drivers to establish a routine and with schedules that run counter to the natural circadian rhythms of drivers. Indicators that reflect drivers' regularity of time include the percent of time normally driven the same daily hours, how driving time is distributed over the 24-h day, the variability of driving work, and the maximum hours driven in a given week.

Quality of rest captures when and where drivers are able to obtain uninterrupted sleep and the duration of such sleep. The eight items in the model reflect when and where drivers get sleep, the level of difficulty in finding a place to rest, how much sleep they get, and the amount and effectiveness of recovery time between runs.

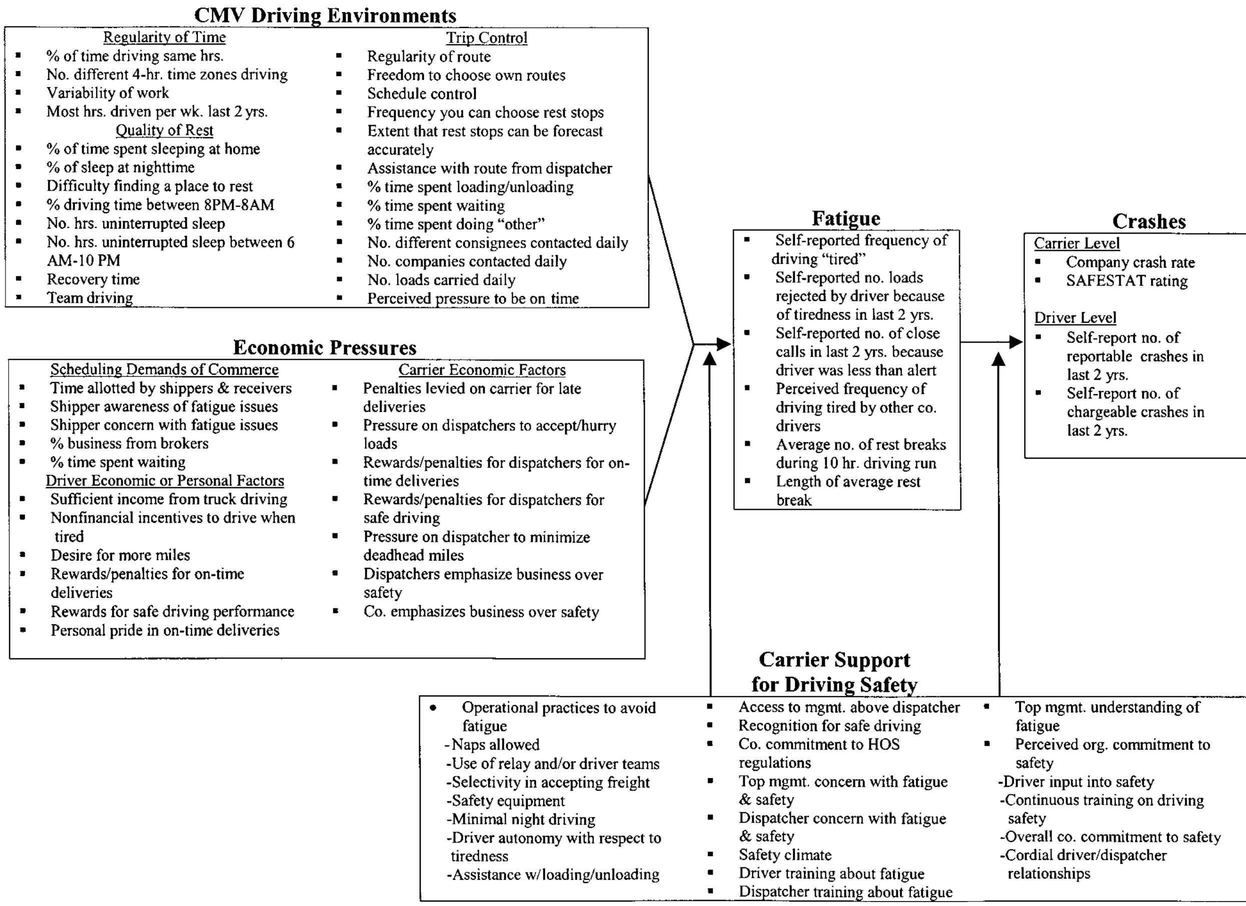

FIGURE 1 Proposed CMV driver fatigue model (HOS = hours of service).

Trip control measures reflect the ability of drivers to plan trips and how closely trips conform to what was expected, and the percentage of time spent performing job-related activities other than driving. Measures formulated to capture trip control include the regularity of driver routes, driver control over routes and schedule including rest stops, dispatcher assistance in determining the best routes to drive, and the number of stops per day. Additionally, the model includes nondriving factors, such as the percent of time spent waiting and loading or unloading, the percent of time spent on other nondriving activities while working (e.g., paperwork), and perceived pressure to be on time.

The literature provides a great deal of support for the ideas represented in the CMV driving environments category. Crum et al. identified 10 studies that discussed how drivers' irregular work schedules are related to fatigue and 17 studies that emphasized how driver difficulties in getting adequate rest while working lead to fatigue (*1*). They also identified 18 studies that discussed how the inability of drivers to control many elements of their work contributes to fatigue.

Similarly, the focus groups were consistent with the literature for identification of factors contributing to driver fatigue. The scheduling demands of commerce, trip control, and company support for safety were identified as key factors by each focus group. They viewed driving environments and the economic pressures exerted on drivers as equally important.

Fatigue and Safety Outcome Measures

Two categories of dependent variables are included in the model.

Driver Fatigue There is little consensus in the literature regarding how driver fatigue should be viewed and measured. Numerous indicators of perceived driver fatigue are possible, although care must be taken to obtain these estimates in ways that minimize self-incrimination and elicit accurate responses. Williamson et al. (*2*) noted that although many drivers acknowledge that fatigue is an industrywide problem, fewer admit that fatigue is a problem for them personally. Accordingly, a broad array of direct and indirect fatigue indicators were included. Frequency of driving tired is the first indicator and it was used in research by Williamson et al. (*3*), Harris and Mackie (*4*), and Mackie and Miller (*5*). Harris and Mackie used other fatigue indicators germane to this study, including the number of close calls experienced by the driver because of less-than-full alertness and an estimate of the frequency with which other company drivers drive when they are tired.

Crash Rates At the individual driver level, crash rate indicators of safety performance include the number of reportable crashes and the number of chargeable crashes a driver has had over some defined time or mileage period. Harris and Mackie (*4*) and Mackie and Miller (*5*) were successful acquiring such data via surveys.

Data Collection and Sample

This study sought to be representative of all over-the-road commercial truck drivers. However, the population of such drivers cannot be specified (i.e., there is no directory of all truck drivers). Consequently, sampling was conducted to avoid systematic bias in the selection of drivers.

Data Collection

With the assistance of the National Association of Truck Stop Operators, four large, geographically dispersed truck stops or plazas were identified. These facilities are located near major intersections of Interstate highways and are not dominated by any client, commodity, or product group. They are located in Maryland, Georgia, California, and Iowa. A fifth truck stop in Colorado was added to reach the target sample size of 500. The data collection occurred between October and December 1999.

On the basis of traffic flow through the facility, project staff exercised judgment regarding the frequency with which they randomly asked a driver to participate and how long to remain at a facility. Data collection took place throughout the 24-h day. Drivers were offered $10 cash inducement to participate. Tracking nonrespondent bias would have interfered with an individual's right not to participate and was not attempted.

The number of respondents from the various truck stops were as follows: Maryland, 103; Georgia, 149; California, 128; Iowa, 95; and Colorado, 31. In all, 506 truck drivers participated in the survey, and 502 of these were usable. The overall effective response rate was 97.3 percent (i.e., 502/516) as only 10 drivers declined to participate.

Sample

The composition of the sample can be described in several ways. Demographically, it was overwhelmingly male (89 percent) and ranged in age from 21 to 72 years, with an average age of 41. The average driver had 11.67 years of driving experience and had worked for one or two companies during the previous 2 years.

Sample drivers can also be characterized according to driving characteristics. Most drivers worked for for-hire carriers (86 percent), not private fleets. Company drivers made up 60 percent of the sample, whereas just over one-third (34 percent) were owner-operators. The remainder were temporary, casual, or leased drivers. The overwhelming majority of the drivers (95 percent) drove tractor-trailers, and about a quarter (29 percent) indicated that they typically drove double-combination vehicles. Only 4 percent reported driving longer combinations (e.g., Rocky Mountain doubles or triples). A sleeper berth was available to half (53 percent) the drivers. A majority (65 percent) said that they never engaged in team driving. However, 18 percent said they always worked in a team-driving configuration, and 17 percent engaged in team driving sometimes. Nearly all (93 percent) the respondents described their runs as primarily interstate. The average distance driven per week was estimated to be 4583 km (2,848 mi). The average number of stops for pickups or deliveries was 2.39 per day.

Finally, 80 percent reported that they had not had a reportable crash and 93 percent had not had a chargeable crash in the previous 2 years. The raw data on crash rates were normalized to account for the amount of crash risk exposure a driver experiences. Crash rates were normalized by dividing the number of crashes by the average number of miles driven and were expressed per 160 934 km (100,000 mi). The normalized distribution of crash rates was essentially equivalent to the unadjusted distribution. The 20 percent who acknowledged reportable crashes had between 0.17 and 2.75 crashes per 160 934 km. The 7 percent who reported chargeable crashes had between 0.20 and 2.75 chargeable crashes per 160 934 km.

Selecting Indicators for Environmental Characteristics

Each of the 25 possible indicators was first evaluated to ensure that it yielded sufficient variability among the drivers to be of interest. Beyond this, however, no assumptions could be made about how indicators of a given construct would be related to each other. The relative independence of the indicators precluded the use of standard data reduction techniques like factor analysis. An indicator's association with fatigue and crash behavior was thus used to select those indicators to be further investigated.

The survey contained 15 items related to fatigue and crash behavior:

- Close calls (near accidents) because of a lack of alertness at four fixed locations,
- Close calls because of a lack of alertness at two driving locations,
- Five assessments of fatigue and alertness while driving,
- Two perceptions of the extensiveness of the fatigue problem among other drivers, and
- Two crash-involvement indicators.

The ability of each environmental indicator to account for variation in the fatigue and crash measures was ascertained, and indicators failing to account for a statistically significant (at $p \leq .05$) amount of variation in at least two outcomes were eliminated from further consideration. The significance standard was relaxed to $p \leq .10$ twice to allow retention of two measures that are uniquely descriptive of driving behavior (i.e., the number of different 6-h time zones driven daily and route regularity). Following this procedure, indicators were evaluated for excessive multicollinearity (i.e., > .4). However, no indicators were eliminated on the basis of this criterion. These procedures yielded a much more efficient model consisting of 12 indicators.

Regularity of Time Indicators

Regularity of time refers to the extent to which drivers can achieve a set pattern of driving behavior. The literature and industry experts suggest that drivers who can regularize their time behind the wheel should be able to drive more safely. The first indicator, a subjective estimate of how often they drive the same hours, revealed that just over one-third (38.8 percent) of the sample was "never" or "rarely" able to start and stop driving the same time each day. The remaining 61.2 percent said they were able to do this "sometimes," "frequently," or "always."

Regularity of time can also be viewed in terms of the variability of the driving experience. Four daily work time zones were created by dividing the workday into four 6-h periods (starting at 6:00 a.m.). A driver was considered to drive regularly during a given time zone if more than 10 percent of his or her driving time occurred during that time zone. The vast majority of drivers reported driving in three times zones: 6:00 a.m. to noon (73.3 percent), noon to 6:00 p.m. (73 percent), and 6:00 p.m. to midnight (69.3 percent). The only time zone with a different utilization pattern was midnight to 6:00 a.m.; just under half (45.7 percent) reported that they normally did not drive these hours, and just over half (54.3 percent) said that they did drive during these hours. The variability of the driving experience was measured simply by counting the number of time zones reported by each driver (i.e., one to four zones). Very few drivers (10.9 percent) drove during only one time zone. One-quarter of the drivers (25.3 percent) reported extensive variability in their driving behavior by reporting that they normally drove during all four time zones.

These two indicators were significantly related to four fatigue and crash outcome measures (at $p \leq .05$), and they explained between 2 percent and 4 percent of the variation in these measures. Driving the same hours was a stronger individual predictor than the number of time zones. As expected, routinely driving the same hours was negatively related to perceptions of fatigue, continuing to drive when less than alert, and perceptions that fatigue is a companywide problem for drivers.

Trip Control Indicators

Trip control entails the amount of discretion and flexibility drivers have while engaged in driving. Six indicators emerged as useful predictors of fatigue and crash outcomes.

The first indicator was regularity of route, the extent to which drivers drive the same routes frequently. About half (45.9 percent) of the study drivers fell into this first category, whereas the remaining (54.1 percent) were classified as driving a wide variety of routes. Freedom to choose own routes was the second indicator. Sample drivers appeared to be afforded more latitude in this area of work, as a large majority (84.4 percent) reported high levels of flexibility.

The third indicator was number of loads taking longer than expected to load or unload. Loading and unloading are integral parts of the driving environment. There is debate about whether these activities increase fatigue emanating from the physical work or offset fatigue induced by otherwise long periods of driving. Additionally, not being able to accurately forecast the amount of time loading or unloading will take is thought to contribute to fatigue and stress. It makes arriving on time for the next pickup or delivery problematic and can lead to perceived pressure to make up time by driving faster or longer. Longer-than-anticipated load times also make planning for rest stop times and locations difficult. Thus this trip control indicator focuses on the number of loads where waiting time is longer than forecast by the driver. Operationally, drivers who wait longer than anticipated for 30 percent or more of their loads were deemed to have less trip control. More than half (52.6 percent) were in this group.

Difficulty in finding a place to rest was the fourth indicator of trip control. It is intuitive that not being able to stop when tired could be a major determinant of fatigue and crashes. The extent to which drivers experience this problem was measured by classifying drivers into two groups: those who never, rarely, or sometimes have difficulty finding a place to rest (51.3 percent), and those who report this to be frequently or always a problem (48.7 percent).

The fifth indicator, schedule delays, consisted of the percent of work time spent in traffic delays or waiting to make a pickup or delivery. Like the experience of long load times, schedule delays contribute to fatigue and the potential for crashes by initiating a sequence of events that can occur when a driver is behind schedule (e.g., pressure to make up time, delaying rest, and forgoing planned rest locations). Drivers reported that between 0 and 90 percent of their work time was consumed by scheduling delays, with an average of 18.3 percent.

The final indicator of trip control was the average number of stops a driver made each day. Again, there is debate about the effect stops have on fatigue. Stops can break the monotony of driving, but they provide more opportunity for unanticipated delays. About half the sample (51.4 percent) reported making one or fewer stops per day on average, and 48.6 percent reported making two or more.

Trip control was significantly related (at $p \leq .05$) to 10 fatigue and crash outcomes, explaining between 4.5 percent and 9.3 percent of the variation in these outcome variables. Five of the six trip control indicators were significant predictors for at least one of the outcome measures. Longer-than-anticipated loading times was the single best predictor for four of the outcome measures. Average number of stops per day was the single best predictor for three measures. Difficulty in finding a place to rest was the single best predictor for two measures.

Quality of Rest

Quality of rest pertains to a driver's ability to obtain good-quality sleep and rest while working. Quality of rest is especially important in truck driving work because of the need for alertness, the long hours driving can entail, the frequent requirement to sleep away from home, and the need to sometimes drive during hours that are counter to circadian rhythms. Four indicators are examined.

The frequency with which drivers are able to get their sleep at nighttime is the first indicator. A majority of the sample drivers (60.9 percent) reported that they were able to sleep at night never, rarely, or sometimes. The remaining drivers indicated that they were able to sleep at night frequently or always. The second indicator was the amount of uninterrupted sleep that drivers typically were able to get during a 24-h period when working. About a third (35.3 percent) said they were able to get 5 or fewer hours of sleep, and nearly two-thirds (64.7 percent) were able to get more than 5 h sleep. The extent to which drivers are able to get home was the third indicator of quality of rest. The sample was nearly equally divided, with 52.6 percent away from home more than 2 weeks at a time and 47.4 percent able to get home at least once every 2 weeks. The final indicator was the frequency with which the driver reported starting the workweek feeling tired. Approximately one-third (38 percent) indicated that they never or rarely started tired, whereas almost two-thirds (62 percent) indicated that they sometimes, frequently, or always started tired.

Quality of rest was significantly related to eight fatigue and crash outcomes, explaining between 2.1 percent and 15.2 percent of the variation. Furthermore, each of the four indicators was a significant predictor for at least one outcome measure.

The most pervasive finding was the predictive strength of starting the workweek tired. It was significantly related to eight outcomes and was the only significant predictor for three of the outcomes. For example, starting tired itself explained 12 percent of the variation in self-reported feelings of fatigue.

The frequency with which the driver gets home was a significant predictor for three outcome measures. Interestingly, getting home more often was associated with more close calls, a higher frequency of nodding off while driving, and more reportable crashes.

Refinement of Fatigue and Crash Outcomes

The 15 fatigue and crash indicators specified in the model have thus far been treated as single-item outcomes. This was useful for a very in-depth understanding and for refining the independent variables, but it is rather tedious in presentation. As in the case of the driving-environment indicators, a reduction in the number of dependent variables would result in a more efficient model. Unlike the independent variables, however, an examination of the 15 outcome indicators suggests some natural groupings may exist. Conceptually, the close-call items appeared to be a logical grouping, whereas the two crash items (i.e., reportable and chargeable) appeared to be a second logical grouping. The remaining items, reflective of perceptions of personal and others' fatigue, constituted a third possibility. Accordingly, factor analysis was employed.

Table 1 shows the results of the factor analysis of the dependent variables. The close-calls items were unidimensional. The Cronbach alpha associated with the six items ($\alpha = .81$) further supported the unidimensionality of the measure. This newly formed measure was named *frequency of close calls.*

Table 1 also shows that the perceptions of fatigue items have a unidimensional factor structure. These six items also yielded a Cronbach alpha ($\alpha = .80$) indicative of a single factor. Accordingly, these six items were combined to form a measure called self and others' perceptions of fatigue.

The results of the factor analysis for the two crash involvement indicators yielded a single-factor solution. The two items were then combined to form a single measure. The Cronbach alpha associated with the new crash involvement measure was .76.

Figure 2 illustrates the driving-environment model with the reduced number of driving-environment indicators and the revised fatigue and crash outcome indicators. In addition, Table 2 reports the descriptive statistics for all the variables included in this model. Table 2 indicates that nearly all the variables were characterized by reasonable dispersion relative to their range. Only crash involvement appeared to suffer from restriction in range. This restriction in range indicates that it will be difficult to achieve statistically significant findings for analyses involving crash involvement. In other words, the relative infrequency of crashes makes the prediction of this outcome very difficult. However, given the criticality of crash involvement, it was retained.

TABLE 1 Results of Factor Analysis of Fatigue Outcome Measures

Frequency of Close Call Items	Factor
At a terminal	.69
At a weigh station	.65
At a truck stop	.78
At a shipper/receiver facility	.76
While driving in urban area or secondary road	.75
While driving on interstate	.66
Eigenvalue/Percent of Variance Explained	51.38
Perceptions of Fatigue as Problem Items	**Factor**
Near misses because of fatigue	.63
Nod off while driving	.79
Think fatigue is a problem	.76
Continue to drive when tired	.77
Fatigue is a company problem	.64
Fatigue is an industry problem	.66
Eigenvalue/Percent of Variance Explained	50.67

TYPOLOGY OF WORK ENVIRONMENTS

The three primary characteristics of driving environments and their underlying indicators provide the basis for a typology of driving environments. At present, little is known about the proportions of drivers who work under conditions that are favorable for avoiding fatigue and crashes (i.e., enjoy regularity of time, high levels of trip control, and high quality of rest) and under unfavorable conditions

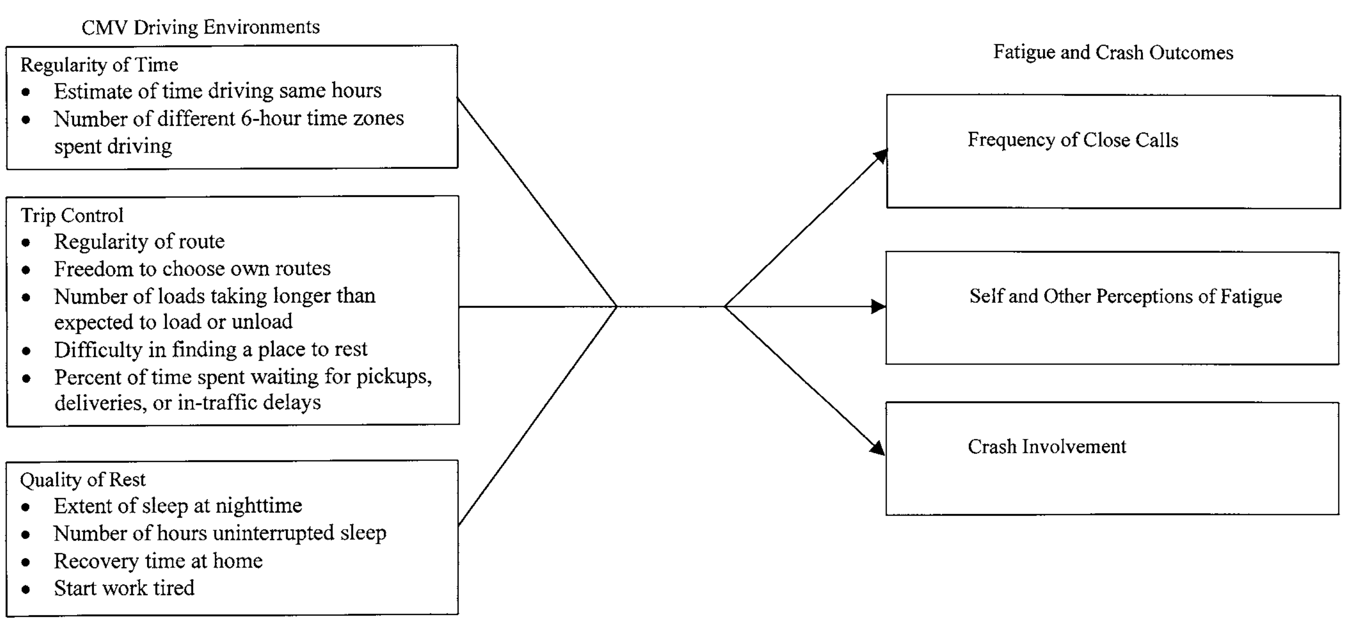

FIGURE 2 CMV driving environments and revised fatigue and crash outcomes of truck drivers.

TABLE 2 Descriptive Statistics for Variables Specified in CMV Driving Environments and Fatigue Outcomes Model

Variable	Range	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Driving same hours	1-2	1.62	.49															
2. Number of time zones	1-4	2.70	.98	-.11														
3. Regularity of route	1-2	1.54	.50	-.15	.06													
4. Choose own routes	1-2	1.84	.36	.01	-.00	.02												
5. Long load time	1-2	1.53	.50	-.06	.05	.01	-.05											
6. Difficulty in rest place	1-2	1.49	.50	-.16	.07	.07	-.01	.15										
7. Schedule delays	0-90	18.31	11.54	-.04	.07	.00	.01	.16	.02									
8. Avg. stops per day	1-2	1.49	.50	-.05	-.00	-.14	.04	.05	.00	.00								
9. Sleep at night	1-2	1.39	.49	.29	-.13	-.02	.06	-.15	-.23	-.07	-.06							
10. Uninterrupted sleep	1-2	1.65	.48	.20	-.05	-.01	.02	-.09	-.10	-.09	-.01	.30						
11. Frequency at home	1-2	1.47	.50	.06	-.03	-.26	.11	-.08	-.09	-.10	.27	.09	.01					
12. Start work week tired	1-2	1.62	.49	-.08	.02	-.04	-.13	.18	.15	.07	.04	.28	-.18	-.08				
13. Close calls	6-28	11.60	3.90	-.08	-.09	-.06	.07	.16	.11	-.00	.02	.07	-.02	-.02	.18	(.81)		
14. Fatigue	6-26	14.80	4.24	-.17	.02	-.09	-.05	.29	.17	.11	.09	.26	-.22	-.04	.40	.43	(.80)	
15. Crash involvement	0-5.49	.13	.36	.02	.02	-.07	-.04	.07	-.01	-.02	.13	-.08	-.05	.07	.12	.06	.12	(.77)

Notes: (1) *N*s ranged from 468 to 502 due to missing data
(2) Cronbach alphas for multi-item scales are on diagonal
(3) Correlations ≥ ±.09 are statistically significant at $p \leq .05$ (2-tailed); correlations ≥ ±.13 are statistically significant at $p \leq .01$ (2-tailed)

(i.e., poor regularity of time, low levels of trip control, and poor quality of rest).

By drawing on the preceding analysis, the single best predictor of fatigue and crash outcomes for each characteristic was identified. The best indicator of regularity of time was the estimate of time driving the same hours. For trip control, the number of loads taking longer than expected to load or unload was observed to be the strongest predictor. Quality of rest was best represented by the frequency with which drivers start their workweek tired. By dividing each indicator into unfavorable and favorable levels, a 2 × 2 × 2 typology containing 8 driving-environment cells was formulated and is presented in Table 3. Each of these environmental cells can be viewed as a way to describe various CMV driver work environments. The typology depicted in Table 3 is one of 48 that could be formulated by using the three driving-environment characteristics and their 12 underlying indicators (i.e., 2 × 6 × 4).

As shown in Table 3, all eight driving environments were represented in the sample. The environment with the largest proportion of drivers (20.1 percent, $N = 100$) was No. 4, characterized by regular driving time but more loads with longer load times than expected and a high frequency of starting the workweek tired. The next most common environment (16.5 percent of the drivers, $N = 82$) was the least favorable. These drivers reported driving irregular times, waiting much longer than they had planned for more loads to be loaded or unloaded, and a high frequency of starting the workweek tired. Collectively, this distribution of drivers in all eight environments suggests that CMV work environments are highly variable and that there is no such thing as a typical work environment.

One-way analyses of variance were completed by using this work environment to predict each of the three fatigue and crash outcomes (see Table 4). Work environment was found to be a statistically significant ($p \leq .001$) predictor for two outcomes—the frequency of close calls and perceptions of fatigue. A visual inspection of the means indicates that these outcomes were higher in the higher-numbered work environments. It appears that the eight driving environments may be viewed somewhat in a continuum fashion with the first environment as the most favorable and the eighth environment as least favorable.

Although not reported here, additional driving-environment typologies were formulated and analyzed with similar results. One combination merits special comment because of its ability to explain variation in crash involvement. The environment defined by driving regularity, number of loads taking longer than expected, and number of hours of uninterrupted sleep, was significantly related ($p \leq .05$) to all three outcome measures. As before, there was a general increased trend toward more undesirable outcomes in the higher-numbered environments. Interestingly, however, the absolute worst scenario for crash involvement ($M = .29$) occurred in the environment characterized by longer-than-anticipated waiting times for loads and 5 or fewer hours of sleep but regular driving times. Fortunately, the

TABLE 3 Distribution of Drivers

	Driving Environment	Frequency	Percent
1.	Drive regular time, low load wait time, do not start workweek tired	72	14.5
2.	Drive regular time, low load wait time, start workweek tired	79	15.9
3.	Drive regular time, high load wait time, do not start workweek tired	53	10.7
4.	Drive regular time, high load wait time, start workweek tired	100	20.1
5.	Drive irregular time, low load wait time, do not start workweek tired	39	7.8
6.	Drive irregular time, low load wait time, start workweek tired	46	9.3
7.	Drive irregular time, high load wait time, do not start workweek tired	26	5.2
8.	Drive irregular time, high load wait time, start workweek tired	82	16.5
	Total	497	100%

percentage of drivers working in this environment (9.1 percent) was relatively small.

DETERMINING HOW DRIVING-ENVIRONMENT INDICATORS AFFECT FATIGUE AND CRASHES

Testing the driving-environment component of the CMV driver fatigue model is somewhat premature because many elements known to affect fatigue and crashes are not included in Figure 2 (i.e., economic pressures and carrier support for driving safety). Still, insights may be gleaned by examining how driving-environment indicators affect fatigue and crash outcomes independent of any specific driving-environment typology. Regression analysis was used to test whether the CMV driving-environment factors were related to fatigue and crash outcomes (see Table 5).

Close Calls

The 12 indicators of driving environment explained 5 percent (F = 2.95, $p \leq .001$) of the variability of close calls due to fatigue. Three indicators, one from each environmental factor, emerged as useful predictors of close calls. The number of different 6-h time zones a driver worked in during a given workweek ($\beta = -.11$, $p \leq .05$) was negatively related to close calls, a rather counterintuitive finding. One would expect more time zones to be associated with a greater frequency of close calls. The results associated with the other two

TABLE 4 Driving Environment as Predictors

Fatigue and Crash Outcome	Range	Driving Environment Means 1	2	3	4	5	6	7	8	F
Close Calls	6-28	10.06	11.09	11.78	12.18	9.97	12.89	11.27	12.67	4.62*
Self & Others' Perceptions of Fatigue	6-26	11.55	14.65	13.33	16.32	12.15	15.76	14.96	17.43	18.17*
Crash Involvement	0-5.49	.00	.11	.00	.21	.00	.16	.00	.14	1.55

$^*p \leq .001$

TABLE 5 Results of Regression Analysis of Fatigue Indicators

Driving Environment Indicators	Close Calls	Self and Others' Perceptions of Fatigue	Crash Involvement
Regularity of Time			
Driving the same hours	-.06	-.10*	.03
Number of time zones	-.11*	-.03	.02
Trip Control			
Regularity of route	-.07	-.09*	-.04
Can choose own routes	.08	.03	-.02
Long load time	.12*	.18**	.05
Difficulty in rest place	.06	.07	-.05
Schedule delays	-.04	.06	-.03
Average stops per day	-.02	.04	.10***
Quality of Rest			
Extent of sleep at night	.01	-.08	-.05
Uninterrupted hours of sleep	.03	-.09*	-.04
Frequency at home	-.01	-.01	.07
Start workweek tired	.18**	.29**	.09***
F	2.95**	11.41**	1.67***
Adjusted R^2	.05	.23	.02

*$p \leq .05$ **$p \leq .001$ ***$p \leq .10$

indicators were in the expected direction. The experience of more than 30 percent of one's loads taking longer than expected to load or unload, a trip control indicator, was positively related ($\beta = .12$, $p \leq .05$) to close calls. Finally, quality of rest, as reflected in sometimes, frequently, or always starting the workweek tired ($\beta = .18$, $p \leq .001$), was also positively related to close calls. Thus, although the total amount of explained variation was modest (5 percent), there is evidence that elements representative of each environmental factor play a role in the frequency of close calls.

Self and Others' Perceptions of Fatigue

Driving-environment factors accounted for 23 percent ($F = 11.41$, $p \leq .001$) of the variation in fatigue perceptions. As in the case of close calls, factors from each environmental set played a role. Drivers who never or rarely drove the same hours had higher perceptions of fatigue ($\beta = -.10$, $p \leq .05$). Trip control yielded two useful predictors. The extent to which drivers experience regularity in the routes they drive was linked to fatigue, and less regularity was associated with more fatigue ($\beta = -.09$, $p \leq .05$). More loads with longer-than-expected load times ($\beta = .18$, $p \leq .001$) was also associated with more fatigue. Quality of rest also produced two predictors of fatigue. Drivers who reported getting 5 or fewer hours of uninterrupted sleep when they were working ($\beta = -.09$, $p \leq .05$) or who started the workweek tired ($\beta = .29$, $p \leq .001$) were significantly more likely to report higher levels of fatigue in others or themselves.

Crash Involvement

The ability of the three environmental factors to account for variation in actual crash involvement was small and only marginally statistically significant (i.e., 2 percent, $p \leq .07$). Recall, however, that achieving statistical significance was predetermined to be difficult, given the low base rate of crashes (i.e., the restriction in range association with the crash involvement measure). The two predictors of crashes came from the trip control and quality of rest categories. The average number of stops per day (as measured by one or fewer versus two or more) was positively ($\beta = .10$, $p \leq .10$) related to the number of crashes, and starting the workweek tired also contributed to the explanation of crashes ($\beta = .09$, $p \leq .10$).

DISCUSSION OF RESULTS

The primary objectives for this paper were to develop a typology of driving environments, to estimate the percent of drivers working in each type of driving environment, and to describe how driving environment affects fatigue and crash rates. The literature review and focus groups of industry professionals led to the development of 25 potential indicators of truck driving environments. A survey of randomly selected truck drivers provided the required data.

Twelve driving-environment indicators were found to be meaningfully related to 15 fatigue and crash outcome measures: two regularity-of-time items, six measures of trip control, and four items indicating quality of rest. Factor analysis identified three constructs underlying the 15 fatigue and crash measures: close calls due to fatigue, the perception of fatigue as a problem for self and other drivers, and crashes (reportable and chargeable).

Because all three hypothesized driving-environment characteristics were good predictors of fatigue, each was used to develop various $2 \times 2 \times 2$ typologies of driving environments. An eight-cell typology based on the strongest single predictor of fatigue from each of the three driving-environment characteristics was created, and its ability to predict fatigue and crashes was assessed. Each possible driving-environment cell was represented by some sample drivers, with 16.5 percent of the drivers in the environment most conducive to creating fatigue and crashes.

This particular typology does a good job of predicting the frequency of close calls due to fatigue and drivers' perceptions of fatigue being a problem for themselves and other drivers. It is not as good at predicting crashes, but this is likely because of, at least in part, the low base rate of crashes. Another typology that does predict crashes was identified and briefly discussed. One problem with forming typologies of driver work environments is that it is possible to identify only the best cell with respect to fatigue and safety and the worst cell. The in-between cells are more difficult to assess because of the interactive effects of the fatigue indicators.

Finally, regression analysis was used to determine the effect the 12 driving-environment indicators have on fatigue and crashes. The model provided statistically significant results for the two fatigue outcome measures and marginally significant results ($p \leq .10$) for the crash measure. Starting the workweek tired was a significant predictor for all three dependent variables and positively related to each. Longer-than-expected loading or unloading times was a significant predictor of close calls and perceptions of fatigue and positively related to each.

These results suggest several implications relative to the role of truck driving environments in reducing driver fatigue:

- Carriers should focus on providing adequate recovery time for drivers between driving stints.
- Drivers should use the provided recovery time to obtain adequate rest to begin the next driving period refreshed and alert.
- Shippers and carriers need to work together to improve the scheduling and performance of loading and unloading activities.

Additionally, driving the same hours each day and obtaining at least 5 h uninterrupted sleep between driving stints were significant predictors of drivers' perceptions of fatigue as a problem. Thus, the results support the conventional wisdom that putting drivers on regular time schedules helps reduce fatigue. The importance of an adequate amount of quality sleep is also highlighted by these findings. This study used 5 h uninterrupted sleep because it was the median for the sample drivers. This should not be construed as the optimal amount of sleep necessary to avoid fatigue.

In conclusion, this study indicated that the driving environment plays a key role in driver fatigue. It also revealed that a large percentage of drivers are at high risk for experiencing fatigue on the job. The CMV driver fatigue model presented in this paper hypothesizes other fatigue-influencing factors (i.e., economic pressures and company practices and programs that promote safety) that were not investigated. Research on the effects of these factors would provide additional useful insights on the issue of driver fatigue.

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