POTENTIAL CAUSES OF DRIVER FATIGUE: A STUDY ON TRANSIT BUS OPERATORS IN FLORIDA

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ABSTRACT

This research study examines the safety impacts of the existing operator hours of duty policies in the state of Florida. Thus, this study uses questionnaire surveys, incident data archived by transit agencies and bus driver schedules to determine the relationship between crash involvement and operator schedules. Factors of interest in this study are the influence of shift pattern (start and end time), schedule pattern (split or non – split schedule) and time spent on driving. The study revealed that, operators working split schedules are more susceptible to fatigue than those working straight schedules. The group of operators working split schedules indicated less time of sleep, long driving hours and early starting – late ending schedule patterns. These the characteristics of fatiguing work schedule. There is also a strong statistical significance (p-value <0.001) attached to the association between crash occurrence and fatigue condition (red, yellow or green), with red condition contributing significantly to the total crashes (56.48%). Suggestion is made for the transit agencies to establish fatigue countermeasures through the use of fatigue detective technologies and policies.

INTRODUCTION

According to the literature, there are many definitions of driver fatigue. The words “fatigue”, “sleepiness” and “drowsiness” are often used interchangeably. Sleepiness can be defined as the neurobiological need to sleep resulting from physiological wake and sleep drives *(1)*. Fatigue has from the beginning been associated with physical labor, or in modern terms task performance. Although the causes of fatigue and sleepiness may be different, the effects of sleepiness and fatigue are very much the same, namely, a decrease in mental and physical performance capacity.

LITERATURE REVIEW

Fatigue is a steady and increasing process linked with reluctance towards effort, ultimately resulting in reduced performance effectiveness. The major symptom of fatigue is a general sensation of weariness *(2)*. We know from everyday experience that fatigue has different causes. The most common is intensity and duration of physical work. Grandjean *(2)* visualized the degree of fatigue as an aggregate of all the different stresses of the day, in the form of a barrel partly filled with water; the recuperative rest periods would be the outflow from the barrel. To ensure that the barrel does not overflow we must guarantee that inflow and outflow are of the same order of magnitude. In other words, to maintain health and efficiency the recuperative processes must cancel out the cumulated fatigue. Recuperation takes place mainly during night-time sleep, but free periods during the day, and all kinds of pauses during work, also make their contribution *(2)*.

Fatigue leads to a deterioration of driving performance, manifesting itself in slower reaction time, diminished steering performance, lesser ability to keep distance to the car in front, and increased tendency to mentally withdraw from the driving task *(8)*. The withdrawal of attention and cognitive processing capacity from the driving task is not a conscious, well-planned decision, but a semi-autonomic mental process of which drivers may be only dimly aware *(8)*. Drivers may try to compensate for the influence of fatigue, for instance by either increasing the task demands (e.g. driving faster so that a ‘new’ sensation of driving spurs adrenaline and attention levels) or lowering them (e.g. increasing the safety margins by slowing down or using larger following distances). But crashes and observations of driving performance show that compensatory strategies are not sufficient to remove all excess risk *(8)*.

The most general factors that cause fatigue are lack of sleep, bad quality sleep and sleep demands induced by the internal body clock. Besides these general factors, prolonged driving (time-on-task) can increase driver fatigue, especially when drivers do not take sufficient breaks. For specific groups of drivers, e.g. professional drivers, these general factors often play a more persistent role due to long or irregular work schedules. A small part of the general population (3-5%) has to cope with obstructive sleep apnea, a sleeping disorder which contributes to above average day-to-day sleepiness *(8)*.

Driver fatigue can be classified into two subcategories, sleep-related (SR) and task related (TR) fatigue on the basis of causal factors contributing to the fatigued state *(3)*. Sleep deficiency, extended duration of wakefulness and time of day affect SR fatigue. Certain characteristics of driving, like task demand and duration, can produce TR fatigue in the absence of any sleep-related cause *(3)*. However, TR fatigue is specifically subcategorized into active TR fatigue and passive TR fatigue. Generally, the causing factors of TR fatigue are the driving task and driving environment. In particular, active TR fatigue is caused by increased task load, high density traffic, poor visibility and the need to complete secondary task while the passive TR fatigue is due to underload condition, monotonous drive, extended driving periods and automated systems. May and Baldwin *(3)* cited the publications by Desmond *et al. (4)* as well as Gimeno *et al. (5)* pointing out that driver fatigue can be produced by active or passive TR fatigue. Active fatigue is the most common form of TR fatigue that drivers experience *(4)*. Gimeno *et al*. *(5)* relate active fatigue to mental overload (high demand) driving conditions and passive fatigue with underload conditions. Typical environment of high task demand situations include high density traffic, poor visibility, or the need to complete an auxiliary or secondary task (i.e. searching for an address) in addition to the driving task*(3)*. Passive fatigue is produced when a *driver* is mainly monitoring the driving environment over an extended period of time when most or the entire actual driving task is automated. Passive fatigue may occur when the driving task is predictable. Drivers may start to rely on mental schemas of the driving task which results in a reduction in effort exerted on the task *(5)*. Underload is likely to occur when the roadway is monotonous and there is little traffic *(3)*.

Most researchers of driver fatigue have been directing their focus towards sleep deprivation or circadian rhythm effects, but require drivers to perform driving tasks in automated environments and monotonous highway conditions. This confounds the effects of SR and TR fatigue. May *et al. (3)* put it clear that driver fatigue does absolutely produce performance decrements in driver simulation and on-road driving tasks. Figure 1 is the fatigue model illustrating the three types of fatigue, their causes, consequences and interactions.

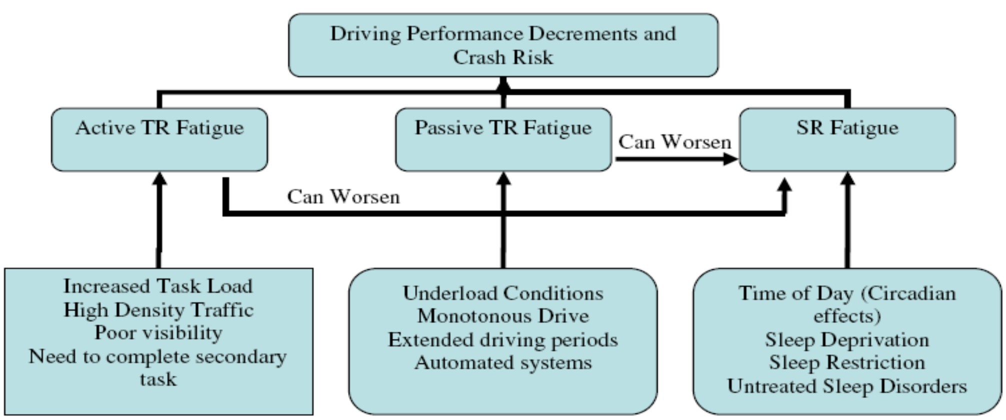

FIGURE 1 Fatigue Model, Source *(3)*

The model shows that active and passive TR fatigue can worsen SR fatigue. All three types can directly cause driving decrements and crash risk. Most studies that have investigated the influence of long hours of driving on safety for trucks have examined the presence of sleepiness and fatigue in truck drivers. McCartt *et al*. *(6)* conducted face-to-face interviews with 593 long-distance truck drivers at rest areas and inspection points. The study found that six factors that were studied had influence on drivers falling asleep at the wheel. The six factors are (1) greater daytime sleepiness (2) more arduous schedules with more hours of work and fewer hours off-duty (3) older, more experienced drivers (4) short, poorer sleep on road (5) symptoms of sleep disorder, and (6) greater tendency to night-time drowsy driving. The study further suggested limiting drivers' work hours and enable drivers to get adequate sleep to reduce sleepiness-related driving by truck drivers. Williamson *et al*. (7) conducted a controlled experiment whereby he examined twenty seven professional truck drivers who completed a 12-hour, 900 km trip under three different settings – relay trip, a working – hour regulated one-way single trip, and a one-way (flexible) trip with no working hours constraints. The results of the study indicated indifference in fatigue for the three different settings. However, the study suggested that the fatigue patterns were more related to pre-trip fatigue levels.

In another publication, Feyer and Williamson *(7)* pointed out that although fatigue is a problem for coach drivers, it is not of the same order of magnitude as for truck drivers. The authors argue that operationally, bus drivers are not as free as truck drivers to take rest on a needs basis. Virtually for all bus drivers, their work is scheduled by someone else, both during the course of the trip and for the endpoints. Scheduled stops throughout the trip are part of the commuter nature of express passenger operations. The needs to meeting passenger schedules largely eliminate any flexibility for bus drivers to take rest on a needs basis.

RESEARCH OBJECTIVE

This research study examines the safety impacts of the existing operator hours of duty policies in the state of Florida. Thus, this study uses questionnaire surveys, incident data archived by transit agencies and bus driver schedules to determine the relationship between crash involvement and operator schedules. Factors of interest in this study are the influence of shift pattern (start and end time), schedule pattern (split or non-split schedule) and time spent on driving. The outcome of this study will be used by transportation officials from state to local transit agencies in determining how best to schedule bus operator hours in order to reduce safety risks that might be caused by operator fatigue.

RESEARCH METHODOLOGY

Two different procedural approaches for gathering and analyzing relevant information were employed. The two methods employed were (1) Survey questionnaire; (2) Analysis of transit agencies' incident reports and operator schedules. Detailed discussion of each of the two approaches is described in the following sections.

ANALYSIS OF SURVEY QUESTIONNAIRE DATA

Questionnaire Design

A survey of bus operators was conducted to collect information on how operators use break time (for split shifts) and activities performed during the off-duty hours after and before beginning work. Two different questionnaires were prepared. The first questionnaire solicited information on typical activities performed by operators during breaks between split shifts. The objective of this questionnaire was to determine whether the break between split shifts is used for resting and possibly establish the relationship between the length of the break and type of typical activities performed during the break.

The second questionnaire was designed to gather information of activities performed during the off-duty hours. The objective of this questionnaire was to assess the adequacy of the minimum off-duty period of eight hours. Typical activities that could be performed during the off-duty period may include operators traveling from work to home, eating, sleeping, preparing for work, and traveling back to work from home. The amount of sleep that a bus operator gets would depend on the time it takes to perform off-duty activities. These anonymous surveys used a diary technique to document start and end of each off-duty activity. General questions such as the distance from home to work, average hours of sleep per day were also included in the questionnaire.

Survey Results and Discussion

Length of split break and activities performed during the break

Split shift, is an employment schedule, a type of shift work where a person's normal work day is split in to two or more segments, for example a person may work from 5 a.m. to 9 a.m. and then have a break until 3 p.m. at which point they might return to work until 7 p.m. This is especially common for public transport employees where it is advantageous to have additional staff working during traditional rush hour times. It is generally not a desired shift since one is basically tied to work all day, and one's time in between shifts can be taken up by getting to and from work. For that matter, this is the most fatiguing type of shift among transit bus operators.

In this study, a question was asked to determine whether the operator works split shifts or otherwise. Sixty-one percent of all respondents reported to work split shifts while 37% works straight shifts. The rest of the respondents (2%) seem to work irregular shifts, split or straight shifts for different days. The maximum length of the break between the split shifts was reported to be six hours (2% of the respondents) and the minimum was zero (27%). It was noted that those who reported to have a break of zero hours are those who have a change of routes (or buses) or assigned different duties without having a break in between. This inference is made on the basis an observation made from a few operator schedules collected where some operators seemed to have changes of routes or buses which seemed like a split with a break in between the processes. Majority of the respondents (39%) reported to have a break of three hours. The general picture for the distribution of break lengths is shown in Figure 2.

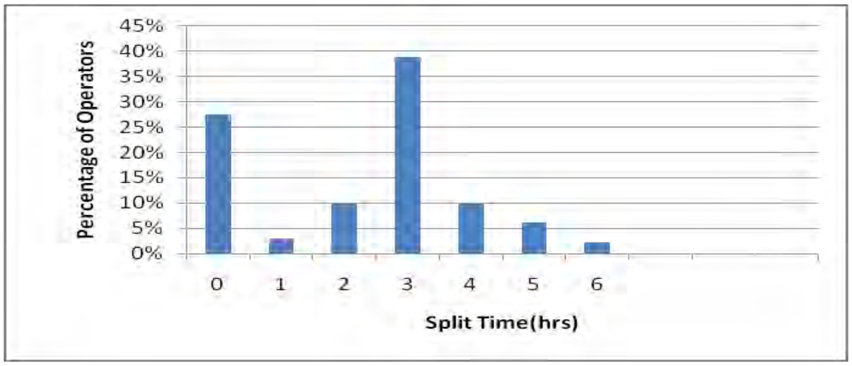

FIGURE 2 Distribution of length of break for the operators working split schedules.

On the question of how the operators spend their break time, it was observed that there were various activities carried out during the break. The operators reported to spend their break time for different activities depending on the length of the break (see Figure 3). Some responded that they used their break time for relaxing, taking a nap or running their personal errands. For analysis simplicity the activities were given the labels as shown on upper case abbreviations in the following sentences. The analysis shows that very small proportions of operators spend their break time for resting (14% relaxing at work site (RWS), 11% relaxing at home(RAH) and 8% taking a nap at work site(NWS), 12% taking a nap at home(NAH)). Instead of spending the break time for resting, significant percentages of operators seem to be engaged in various activities which are probable contributors to driver fatigue. Such activities performed during the break times are performing non driving duties (NDD, 52%), eating at work site (EWS, 46%), shopping and seeing doctors (SDA, 43%) and reading at work site (RDG, 43%). The typical activities performed during the break are reasonably dependent on the length of break time between the splits. It is logic to assume that the group that reported to have the split time of at least two hours is the one which was engaged in activities needing a little longer time to perform such as shopping, seeing a doctor, going home for a nap or relaxing. The group that spent the break time at the work site, most probably belongs to operators having less than two hours of break time which seems less to perform other activities away from the work site.

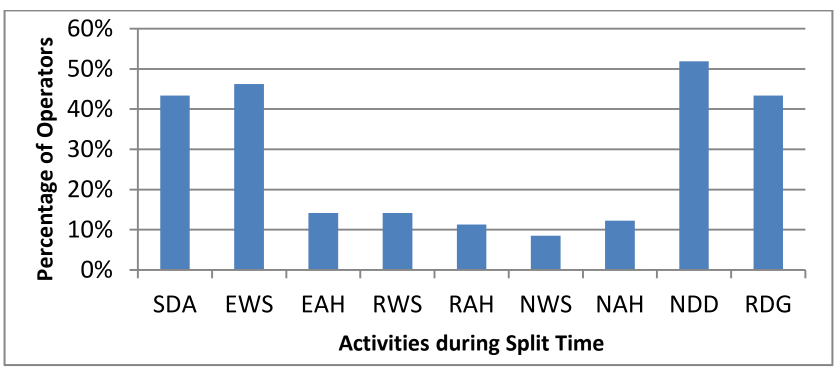

FIGURE 3 Activities performed by operators during the break time between splits

Assessment of the adequacy of the minimum off-duty period of 8 hours

The analyses were performed to assess the adequacy of the minimum off- duty period of eight hours; the responses show that the operators' off-duty period follows the activity diagram as shown in Figure 4. It has been observed that the average times for the activities shown on Figure 4 are as follows: 48 minutes for home to work travel, 43 minutes to travel back home, 353 minutes (about six hours) to do other activities before going to bed. The average time spent on sleeping is 363minutes (six hours) and preparation to go to work after working up is 49 minutes. The overall average time to complete the cycle of off- duty activities is about 14 hours. This is far more than the minimum off-duty period of eight hours stipulated in the FDOT Bus Transit Draft Rule 14-90.006(3).

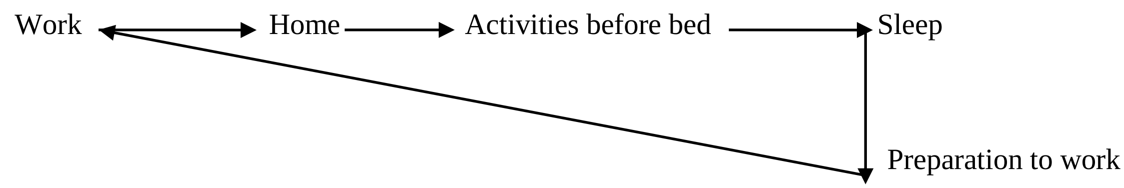

FIGURE 4 Diagram of activities for the operators' off duty period.

The inadequacy of the off-duty period has very serious impact on the drivers' performance due to accumulative nature of fatigue when the resting time is not enough to dissipate the daily state of weariness. It is important to note that the average off-duty period mentioned above was computed based on the entire population of the respondents; situation could be quite different, requiring more off-duty time when considering individual operators. Logically, the amount of sleep that a bus operator gets depends on the time it takes to perform off-duty activities before going to bed. A significant proportion of operators (86%) reported to have less than six hours of sleep within 24 hours. This makes majority of the operators in this study to have lack or poor sleep because scientifically an average person needs eight hours sleep every 24-hour cycle *(8, 12)*. Sleep prior to work is the most prominent factor that influences the waking state, the level of alertness of the driver and reaction time. By the common (and admittedly simplistic) principle that each hour of sleep 'buys' two hours of subsequent wakefulness we would suggest that the ability to 'sustain alertness' is decreased by two hours for each hour of sleep loss *(9)*. Making eight hours as a reference, the computation of sleep debt in terms of hours indicated that most bus operators reported a sleep debt of at least one hour. Further comparison (Figure 5) shows that out of the operators who manifested sleep debt of at least one hour a good proportion (21%) works split schedules. This makes the operators working split schedules more susceptible to fatigue compared to the group working straight schedules.

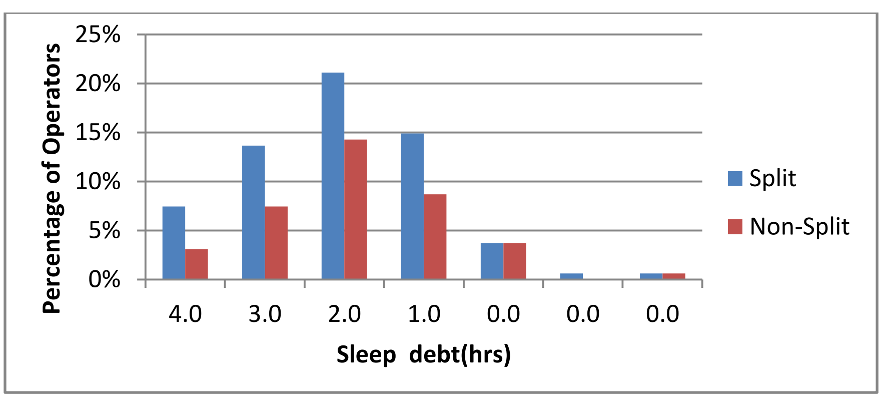

FIGURE 5 Sleep debts among split and straight shifts.

The fatigue-inducing effects of prolonged driving

Prolonged activity inevitably leads to physical and mental fatigue. Researchers have related the duration of activity, or the so called time-on-task, to fatigue symptoms. One of the causes of driver fatigue is the time-on-task, i.e. the time spent driving. For the operators working straight schedules showed to work less hours per day compared to those working split shift. The proportion of straight schedule operators who works for three to six hours was higher compared to split schedule operators. The trend changes from seven to ten hours or more (Figure 6), where 38% of operators work split schedules and were exposed to driving task for more than eight hours per day.

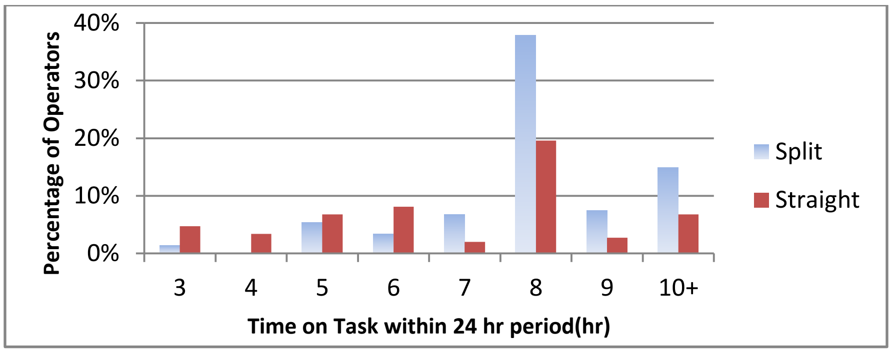

FIGURE 6 Comparison of Time-on-task between split and straight schedules.

For professional drivers, long working hours often go together with early waking and reduced sleep, and then these results suggest that operators working split schedules are usually those having early morning start schedules (3 a.m. to 5 a.m.) The human body has a greater need for sleep at certain times in the 24-hour cycle than at other times (approximately between midnight and 4 a.m.; and, to a lesser extent, 2 p.m. to 4 p.m. At these moments, there is a natural tendency to sleep and, if this cannot be given way to, it leads to accumulated fatigue and a sleepy feeling occurs. Clearly, operators working split schedules are more likely to experience accumulated fatigue and sleepy feelings because they usually have to start working earlier (3 a.m. to 5 a.m.) in order to have a break in between (normally 1 p.m. or 2 p.m.) before they come back for the afternoon shift.

ANALYSIS OF TRANSIT AGENCIES' INCIDENT REPORTS DATA

Most agencies require bus operators to report any incidents including collisions with other vehicles and collisions involving fixed objects. Thus, transit agencies have hard or soft copy reports of these incidents. Most of the crashes involving buses are not archived in the FDHSMV and FDOT crash depository. This is because the FDOT crash database contains crashes that are reported in long forms only. Any crashes which are reported in the short form and driver exchange forms are not found in the FDOT Crash Analysis Report (CAR) system. Therefore, this analysis employed hard and soft copies of incident reports archived locally at the transit agencies' offices.

Data Collection

Operator schedule data were collected in two stages. First, agency-wide operator schedule data were collected to establish the bus operator schedule profiles of the agency operator population. A record of each bus operator included total days worked, on-duty hours, driving hours, and time of reporting on and off duty. Second, schedules for operators who have been involved in collisions that were coded as *"preventable"* collisions were collected. Similar studies in other industries collected a 72-hour history of operator schedule prior to the accident *(10)*.

Data Analysis

This research used Fatigue Audit Interdynamics (FAID®) as fatigue assessment tool. FAID® is a product designed to assist in the assessment of risks associated with workplace fatigue. FAID® is focused on fatigue related to hours of work only *(11)*. As a risk assessment tool, FAID® fundamentally focuses on three basic elements which can combine to create a potentially high risk situation: hours of work (time on task), inadequate sleep (inadequate off duty period), and fatigue related hazards *(11)*. Estimates of work-related fatigue are based on statistical modelling of the amount of sleep likely to be obtained by individuals based on the time of day and duration of work and non-work periods over a seven-day period *(11)*. Indicative fatigue is inferred from estimated sleep obtained. These estimates are based on formulae developed by the Centre for Sleep Research at the University of South Australia and published in international peer-reviewed journals.

FAID® produces a number of outputs ranging from Key Risk Indicators (KRI) to Sleep Estimates (SE). The key outputs of interest for this paper are: (1) FAID® Condition (FC); if Fatigue Tolerance Levels (FTL) is set, then in the Outputs, the work periods FAID® Score is compared to FTL. There are three levels of FAID® Conditions – Red (FAID® Score greater than FTL), Yellow (FAID® Score between –10 and 0 of the FTL) and Green (less than –10 of the FTL). (2) Compliance (used to describe the percentage of time individuals have worked when their indicative fatigue is below the Fatigue Tolerance Level (FTL)). (3) FAID® Score (FS); A relative index of work-related fatigue. (4) Fatigue Hazard; defined as a known characteristic, inherent property, vulnerability, condition or unintended action that represents a potential threat to people, property, the environment or business profitability that can be triggered by fatigued individuals.

Assessment of fatigue accumulation

FAID® Scores are indicators only of the impact of work schedules leading to sleep deprivation and hence fatigue. As they are based on a statistical analysis of research performed into fatigue levels over a broad sample of population, they provide guidance on the fatigue of an individual. The FAID® Scores can be obtained in tabular format (Table 1) or plot (Figure 7). The tabular outputs make it easier to conduct further statistical analyses to develop or investigate the association between the FAID scores and crash occurrences. It is easier to verify the pattern of fatigue accumulation by using FAID® Scores Plot. The plot below (Figure 7) shows fatigue conditions (FAID® Scores) for a particular operator from August 9 through August 31, 2009.

Essentially, FAID® gives such plots for every operator whose work schedules were entered into a system database. Most of the schedules showed plots relatively similar to Figure 7 below.

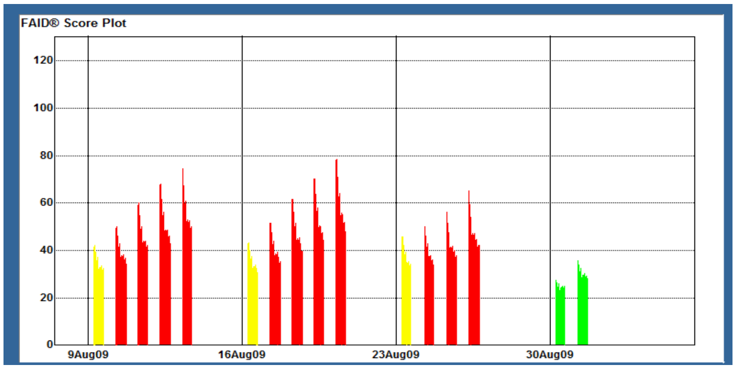

FIGURE 7 Fatigue score plot

The yellow FAID® condition in the first day of the schedule indicates the effects of early start and long hours on task. The early start leads to reduced sleep which is among significant factors which cause fatigue. The effect seems to accumulate more in the next day shifting the fatigue condition into red which is the critical fatigue condition. We can clearly observe from Figure 7 that peak FAID® conditions increase cumulatively for every worked day. The importance of adequate off-duty period and a well-managed schedule can be observed by noticing the difference in FAID® condition on August 16, 2009 (after 2 days of rest) and August 30, 2009 (after 3 days off duty). The schedule starting on August 30, 2009 shows FAID® condition green which means the fatigue that was accumulated all over the previous schedules was completely dissipated within the off duty period. In other schedules prior to that starting on August 30, 2009, just on the first day of the schedule the operator is exposed to yellow FAID® condition implying that the off-duty period was not enough to dissipate the fatigue accumulated in the previous schedules.

The phenomenon of cumulative nature of fatigue calls a need for a strong move toward developing different approaches to ensure an adequate average off duty period and opportunity to obtain sleep for fatigue risk management. Broadly speaking these can be divided into two groups: modified prescription; and fatigue modeling. The most common control process has been compliance with prescriptive hours of service (HOS) rule sets. In spite of the frequent use of prescriptive rule sets, there is an emerging agreement that they are an ineffective hazard control, based on poor scientific defensibility and lack of operational flexibility (Dawson *et al.*., 2005). In investigating potential alternatives, we propose a shift from prescriptive HOS limitations toward a broader Safety management system (SMS) approach which assesses individual's fitness for duty.

Analysis to investigate the association between FAID® conditions and crashes.

To conduct the accident analysis the fatigue conditions output for all operators from FAID® were obtained (see sample output in Table 1) and the operators who were involved in accident(s) were indentified and categorized in three FAID® conditions (green, yellow and red) ; similarly for operators who were not involved in accident(s).

TABLE 1 FAID® score for operator monthly schedule

Non-Work	Start	Work	Task	FAID® Condition Green	FAID® Condition Yellow	FAID® Condition Red	Peak FAID® Score	Peak FAID® Cond
61.8	9 Aug 09 0630	9.7	Moderate	8hr 19min	1hr 23min		43	-7
14.3	10 Aug 09 0630	10.8	Moderate	6hr 47min	3hr 27min	35min	51	1
13.2	11 Aug 09 0630	10.2	Moderate	2min	7hr 22min	2hr 46min	60	10
13.8	12 Aug 09 0630	10.6	Moderate		6hr 19min	4hr 17min	68	18
13.9	13 Aug 09 0700	9.0	Moderate		1hr 2min	7hr 58min	75	25
62.5	16 Aug 09 0630	10.5	Moderate	8hr 54min	1hr 36min		43	-7
13.5	17 Aug 09 0630	11.4	Moderate	7hr 13min	3hr 12min	59min	52	2
12.6	18 Aug 09 0630	10.7	Moderate	17min	6hr 42min	3hr 45min	62	12
13.3	19 Aug 09 0630	10.4	Moderate		3hr 58min	6hr 29min	71	21
13.6	20 Aug 09 0630	10.5	Moderate		29min	10hr 2min	79	29
61.6	23 Aug 09 0635	9.6	Moderate	7hr 36min	2hr 1min		46	-4
14.8	24 Aug 09 0700	10.1	Moderate	6hr 37min	3hr 25min	5min	50	0
13.9	25 Aug 09 0700	11.1	Moderate	2hr 51min	6hr 54min	1hr 21min	57	7
12.9	26 Aug 09 0700	11.4	Moderate		7hr 51min	3hr 33min	65	15
84.6	30 Aug 09 0700	9.0	Moderate	9hr 0min			28	-22

For analysis simplicity the variables for crash occurrence and non-occurrence are coded as Y=1 and Y=0 respectively. The fatigue condition an operator is exposed to and crash frequencies data are structured as a 2x3 contingency table (Table 2) to pose the question: Is there an association between crash occurrence and a particular fatigue condition? The null and alternative hypotheses to test for independence between crash occurrence and FAID® condition variables are written as:

$H_0 : \prod_{ij} = \prod_{i.} \cdot \prod_{.j};$ (Row and column variables are independent)

$H_a : \prod_{ij} \neq \prod_{i.} \cdot \prod_{.j}$ (Row and column variables are dependent) $i = 1, 2; j = 1,2,3$

The test statistic is (distributed as chi-square with degree of freedom $(n_i-1)(n_j-1)$) *(13):*

$$\chi^2 = \sum_{i=1}^{3} \sum_{j=1}^{3} \frac{(O_{ij} - e_{ij})^2}{e_{ij}} \quad (13),$$

Where $e_{ij} = n_{i.} n_{.j} / n_{ij}$. It compares the observed frequencies (O_{ij}) in the table with the expected frequencies(e_{ij}) when H_0 is true .

TABLE 2 FAID® conditions and frequencies of accident occurrence and nonoccurrence

Crash response	FAID® conditions							
	Green		Yellow		Red			
	O_{ij}	e_{ij}	O_{ij}	e_{ij}	O_{ij}	e_{ij}	Total ($n_{.j}$)	$n_{.j}$ /n
Y =1	24	39.250	31	31.750	72	56.000	127	0.577
Y =0	44	28.750	24	23.250	25	41.000	93	0.423
Total ($n_{i.}$)	68		55		97		220	
$n_{i.}$ /n	0.309		0.250		0.441			

$$\chi^2 = \sum_{i=1}^{2}\sum_{j=1}^{3}\frac{(O_{ij} - e_{ij})^2}{e_{ij}} = 42.570, \qquad df = 2,$$

$$p - value = 5.702\,E - 10 < 0.0001$$

As indicated in the table above the FAID® condition and the crash occurrence are significantly associated (p-value <0.001). The calculated chi-square of 42.57 is highly significant exceeding the 0.5% significance threshold, as shown in the bottom of Table 3. Most of the accidents (56.69%) occur when the operators are exposed to red fatigue conditions. The proportion of accidents seems to decrease as the fatigue condition changes from red towards green.

TABLE 3 FAID® conditions and proportions of accident occurrence and nonoccurrence

Crash response	FAID® condition		
	Green	Yellow	Red
Y =1	18.90%	24.41%	56.69%
Y =0	47.31%	25.81%	26.88%

The operators who were in green fatigue conditions show good driving history as indicated by the nonoccurrence proportion (47.31%). Yellow condition shows most interesting results; having about the same proportions for both occurrence and nonoccurrence (24% versus 25.81% respectively). In our opinion, we could choose this fatigue condition as an optimum fatigue condition for the establishment of fatigue management framework. But this calls for further analysis to investigate whether the results would behave the same way.

CONCLUSIONS AND RECOMMENDATIONS

This paper examined the safety impacts of the existing policies related to transit bus operator hours of duty. The research relied on questionnaire survey and analysis of transit agencies' incident reports. The results revealed that most bus operators (61%) work split schedules which is termed as the most fatiguing schedule since operators are basically tied to work all day, and their time in between shifts can be taken up by getting to and from work. It can fairly be surmised from these results that a large proportion of the fatigue related crashes happening to transit buses might be caused by the operators working split schedules. The survey also revealed that the minimum off duty period of eight hours might not be adequate. It is likely that this could be another cause of fatigue among operators because it leads to inadequate rest and sleep. The overall average time required to complete the cycle of off- duty activities was found to be about 14 hours which suggests that within 24 hours the operator has to work for a maximum eight hours in order to have an adequate time to accomplish off duty activities and eight hours of sleep.

The study also found that operators working split schedules are more susceptible to fatigue than those working straight schedules. The group of operators working split schedules indicated that they get less time of sleep, long driving hours and early starting – late ending schedule patterns. These the characteristics of fatiguing work schedule. Moreover, the analysis of transit agencies' incident reports indicated that fatigue increases cumulatively with the number of days and hours worked. The peak fatigue scores for a particular day in a schedule were observed to be higher than the previous day for the same schedule. This is the evidence of cumulative nature of fatigue. The results from this study also indicate that after the accumulation of fatigue, the operator needs enough off duty period to recover from critical fatigue condition. To start with a green fatigue condition (full recovery) in a weekly schedule the operator needs at least two days off duty. In addition, the study revealed that there is a statistically strong association between fatigue condition and crash occurrence (with p-value less than 0.001); a large proportion (56.48%) of accidents associated with operators who were in red fatigue conditions.

These results suggest the need for transit agencies to take initiatives to establish fatigue countermeasures. Fatigue countermeasures may be directed at bus drivers and transit agencies. Bus drivers may learn how to prevent driver fatigue by campaigns. Transit agencies can introduce special policies to educate both drivers and management about the problem. In addition, legislation concerning working and rest hours may be further improved and buses can be equipped with devices that detect fatigue-related decrements in driver performance.

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