SLEEPER BERTH USE IN TWO-UP DRIVING OPERATIONS

Research Paper

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Prepared by

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National Transport Commission

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REPORT OUTLINE

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Objectives:	The Heavy Vehicle Driver Fatigue (HVDF) review is a key component of the Third Heavy Vehicle Reform Package. The aim of this review is to improve road safety through the implementation of policies and practices addressing the management of fatigue in the road transport supply chain.
NTC Programs:	Fitness for Duty, Heavy Vehicle Driver Fatigue
Key Milestones:	This paper is being released as background to the two-up policy proposal. It is being provided for public information only. Public consultation on both draft legislation and revised policies, developed for the heavy vehicle driver fatigue reform, will take place later in 2006 upon receipt of the draft legislation.
Abstract:	The purpose of this paper is to review how team or two-up driving is managed under US and Canadian regulations, and to analyse and discuss the available research on the necessity for driver teams to rest away from their heavy vehicle in order to manage driver fatigue.
Purpose:	Research paper for information purposes only.
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FOREWORD

The National Transport Commission (NTC) is a body established under an inter-governmental agreement with a charter to develop, monitor, and maintain uniform or nationally consistent regulatory and operational reforms relating to road transport, rail transport, and inter-modal transport. The NTC is funded jointly by the Australian Government, States and Territories.

Fatigue is one of the main causes of crashes involving heavy vehicle drivers. The Heavy Vehicle Driver Fatigue Review is a key component of the Third Heavy Vehicle Reform Package. The aim of this review is to improve road safety through the implementation of policies and practices addressing the management of fatigue in the road transport supply chain.

This research paper is being made available in support of the NTC policy proposal on two-up operations.

The position put forward in the two-up policy proposal is subject to change. The NTC will be undertaking further consideration of these issues over the coming months and will advance a final draft Heavy Vehicle Driver Fatigue two-up policy proposal in mid 2006, after consultation with transport agencies and industry.

Final Heavy Vehicle Driver Fatigue draft policy proposals will be made available through the NTC website along with the draft legislation and a regulatory impact statement.

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Michael Deegan

Acting Chairman

SUMMARY

Two-up driving is used to cover ultra long distance trips, to address demands with particular types of freight, for training purposes, and to accommodate tight schedules.

Under the current road transport regulations two-up drivers are covered by the same requirements that apply to drivers operating under Standard Hours. This means that a heavy vehicle can be operated continuously by a two-up team for 6 x 24 hour periods before an extended rest break is required. This is considered to be excessive by fatigue experts.

Two-up has some distinctive advantages over single driver operation such as the presence of another driver in the vehicle which is an instant and very effective countermeasure to extreme sleepiness. With two-up operations most sleep is obtained in *a moving vehicle* on road.

The issue of *quality of sleep in a moving vehicle* is unique to two-up operations. A contentious issue with the NTC proposed two-up policy is the requirement to take a stationary rest break to address the issue of quality sleep in a moving vehicle. However, if two-up teams are being required to stop, at what point in the work cycle should they be required to stop? Fatigue experts are keen to see a long stationary rest break for two-up teams after approximately 36 hours continuous on the road. Existing research indicates that two-up drivers are better able to manage their fatigue than single drivers and to avoid high crash risk situations due to the presence of a second driver.

In the US and Canada, where two-up or team driving is also used to manage long distance trips, the issue of sleep quality in a moving versus a stationary vehicle has not been examined in depth nor has the option of requiring two-up or team drivers to stop at some point in their work cycle to compensate. Dr Knipling, a US based fatigue expert, was approached by the NTC to investigate the available research and summarise some of the operational and safety considerations associated with sleeper berth use in two-up operations.

Dr. Ron Knipling has more than 26 years experience in US highway safety research, with an emphasis on motor carrier (truck and bus) safety. He is an independent consultant whose specialty areas include driver human factors, training, crash analysis, crash causation, naturalistic driving studies, crash avoidance technologies, data analysis, research program management and administration, and safety management. Highlights of his career include four years with Virginia Tech Transportation Institute, six years with FMCSA, six years with NHTSA, and eleven years as a transportation research contractor at Allen Corporation of America where he led transportation-related and other applied research projects.

This paper presents Dr Knipling’s findings.

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1. INTRODUCTION

This paper provides a brief discussion of two-up (also known as team) commercial driving regulations in the United States and Canada and summarizes some of the operational and safety considerations associated with sleeper berth use in two-up operations. Most research, government rulemaking, and debate on sleeper berths and two-up driving in North America has focused on the issue of split-sleep periods, e.g. the splitting of daily mandatory off-duty periods into two or more shorter periods taken in the sleeper berth.

The split-sleep issue is relevant to both two-up and solo commercial driving. Split-sleep periods are addressed here, but the primary focus of the current discussion is on a second problematic aspect of sleeper berth use that is unique to two-up driving: the fact that most sleeper berth use in two-up driving is in *moving* vehicles.

General questions of interest relate to the restorative value of such sleep and the overall impact of driver sleep in moving sleeper berths on the safety of two-up operations.

A particular regulatory question of interest to the NTC is whether two-up drivers should be required to stop their vehicles for periods of sleep at stationary locations during longer multi-day trips. A study by Feyer, Williamson, and Friswell (1997), for example, showed that two-up drivers benefited from mid-trip stationary rest breaks during the homeward leg of long-haul trips.

Other questions relate to how companies can best manage driver fatigue in two-up operations, regardless of whether these management practices are mandated or voluntary.

This paper makes no final regulatory recommendations but rather attempts to review the status of two-up operations and regulations in North America, report major findings from the truck safety research literature, articulate factors favourable and unfavourable to safety in two-up operations, and suggest fatigue management practices applicable to two-up driving.

2. OVERSEAS REGULATIONS

2.1 United States Hours-of-Service and Sleeper Berth Regulations

Federal rules in the U.S. regulating commercial driver Hours-of-Service (HOS) in interstate driving have existed since 1938. The rules were largely unchanged for more than 65 years, but in April 2003 the Federal Motor Carrier Safety Administration (FMCSA) published new HOS rules, which were revisions to Sections 49 Code of Federal Regulations (CFR) Parts 385, 390, and 395 (FMCSA, 2003). The new rules, which went into effect in early 2004, attempted to correct several deficiencies in the old rule, most notably an insufficient daily off-duty requirement for principal sleep and the fact that the old rules tended to encourage a backward-rotating work-rest cycle rather than a 24-hour cycle. Major specific changes to the HOS rules included the following:

- Daily minimum off-duty requirement: 8 → 10 hours
- Maximum hours of driving prior to going off-duty: 10 → 11 hours
- Maximum tour-of-duty (beyond which driving is not permitted) 15 → 14 hours

(Note: Under the new rule, breaks do not extend the maximum tour-of-duty).

- Improved regularity of most daily work/rest cycles as a consequence of the above changes; e.g. 14 hours of work followed by 10 hours off-duty equals 24 hours.
- Weekly maxima: unchanged at 60/70 hours in 7/8 consecutive days (although they may be increased through use of "restart" provision below).
- "Restart": a new provision permitting weekly tabulations to re-set to zero following 34 hours off-duty.

In regard to sleeper berth use, the FMCSA Notice of Proposed Rulemaking (NPRM) in 2000 proposed eliminating the split sleeper berth option (for both two-up and solo drivers), but the rule announced in 2003 reversed that plan and did not change the provision. Thus, drivers using the sleeper berth (whether in a moving or stationary vehicle) were permitted to split their off-duty periods into two or more, shorter, sleeper berth periods, as long as each of these periods was at least 2 hours. The total daily off-duty requirement was increased from 8 to 10 hours, but provisions for splitting the off-duty period when using the sleeper berth were unchanged. Neither the old rule nor the new rule contained any restriction on sleep in a moving vehicle. Whether driving solo or two-up, drivers could split their 10 hours off-duty in the sleeper berth (whether moving or stationary for two-up drivers) in any combination (e.g., 8-2, 7-3, 6-4, 5-5) as long as no period was less than 2 hours.

The U.S. trucking industry as well as many other observers generally supported the above rule changes. The American Transportation Research Institute, research affiliate of the American Trucking Associations, has since published reports supporting their safety effectiveness (e.g., Dick, Hendrix, and Knipling, 2006). Nevertheless, several U.S. safety advocacy organisations filed suit in federal court against the rule and the court ruled in their favour, requiring the agency reconsider the rule with greater deliberation on its impact on the health of commercial drivers (in accordance with the agency's legislative charter). The Court also questioned FMCSA's rationale and justification for several specific HOS provisions, including the split sleeper berth provision. The court proceedings and ruling did not explicitly address sleep in moving vehicles as a separate issue. The U.S. Congress subsequently legislated that the new regulations would remain in effect until FMCSA resolved the issues raised by the Court.

In August 2005, FMCSA re-issued the rule with the sole exception that the split-sleep provision was modified to require a principal sleeper berth period of at least 8 hours in addition to the requirement that all logged sleeper berth periods be at least 2 hours. Thus, for drivers taking the minimum 10 total hours off-duty, the only permitted split is 8-2 (or 2-8). Of course, drivers can take longer periods in the sleeper berth, but this would result in more than 10 total hours off-duty and would reduce productivity.

Although the 2005 rule applies equally to two-up and solo drivers and makes no regulatory distinction between them, the 2005 rule change differentially affects two-up driving since two-up drivers have traditionally split their sleeper berth hours more evenly than solo drivers.

In its Final Rule implementing the change to the sleeper berth split-sleep provisions, FMCSA (2005) cited U.S. Army combat operational studies of sleep duration effects on alertness as well as a 1988 Insurance Institute for Highway Safety (IIHS) study (Hertz, 1988; to be discussed in more detail later in this review) reporting that splitting sleeper berth sleep into two periods of less than 8 hours resulted in a more than two-fold increase in fatal crash risk. FMCSA also cited the 1995 NTSB heavy truck fatigue crash study which found that the duration of the most recent sleep period was the strongest predictor of involvement in a fatigue-related crash versus a non-fatigue crash. In addition, the longer-term negative medical effects of short sleep periods were cited.

Most U.S. trucking companies providing comments to the 2005 rulemaking stated that their two-up drivers generally split their 10 hours roughly evenly (e.g., 5-5, 6-4) and that all drivers need the flexibility to obtain sleep when they are sleepy and when operational situations afford the opportunity for sleep (e.g. when they are waiting to load or unload, or waiting for urban rush hour traffic to clear). Accordingly, the U.S. trucking industry generally opposes the new 2005 sleeper berth rule change and is working to rescind it. The Owner-Operator Independent Drivers Association (OOIDA) has filed suit in federal court against the 2005 restriction, and the Truckload Carriers Association, California Trucking Association, Ohio Trucking Association, and Teamsters union have applied to the court to join OOIDA in its suit. These organisations note that even splits (e.g. 5-5) are a tradition among U.S. two-up drivers because they reduce driving time-on-task and because drivers often report that they cannot actually sleep for longer time periods in a moving vehicle. For both solo and two-up drivers, the new restriction limits flexibility and potentially requires drivers to extend off-duty periods for several hours beyond the time when drivers awaken and want to drive.

Currently, the rule requires that drivers who are off-duty in the berth physically remain in the berth for the full 10 hours of their off-duty time (regardless of split). The U.S. ATA has petitioned the government to allow off-duty drivers to sit in the forward jump seat during the period if they are awake and cannot sleep.

Outstanding research questions relating to the 2005 rule include whether the requirement for longer principal sleeper berth periods extends actual sleep and improves its quality, and more generally whether the required 8-2 split actually increases driver alertness. The U.S. ATA and ATRI are considering further empirical research to address these issues. ATRI has already put out a call to fleets to provide general data on the safety of two-up operations in comparison to solo operations to substantiate the industry position that two-up driving is generally safer than solo driving and therefore should not have been targeted for restrictive regulations.

The above discussion relates to the overall HOS rules and sleeper berth split-sleep provisions. There has been little discussion in U.S. of requiring two-up vehicles to periodically stop for driver rest or to otherwise differentiate between sleep in moving versus stationary vehicles. A review of the 2000 FMCSA HOS Notice of Proposed Rulemaking (NPRM), 2003 Final Rule (implemented in early 2004), and 2005 Final Rule (implemented in late 2005) found no explicit consideration of the question of sleep in moving versus stationary vehicles. Findings are cited relating to the poorer quality of sleep in moving vehicles (e.g. the Virginia Tech Transportation Institute sleeper berth study, to be discussed below) but neither the FMCSA nor any organisations cited by FMCSA have proposed requiring distinctions to be made between sleep in moving versus stationary vehicles or otherwise requiring limiting sleep in moving vehicles.

2.2 Canadian Hours-of-Service and Sleeper Berth Regulations

Canada is currently in the process of enacting legislation to revise its HOS rules at the federal, provincial, and territorial levels. The federal regulation has been completed and is available at

http://canadagazette.gc.ca/partII/2005/20051116/html/sor313-e.html.

The new Canadian HOS rules are scheduled to be fully implemented across the country by January 1, 2007. Table 1 below, provided by Transport Canada, summarises various elements of the new Canadian HOS rules in relation to the U.S. rules.

Table 1. Comparison of Key Proposed Changes to the Canadian and U.S. Hours of Service Rules

Main Provisions	Current Canada	Proposed Canada	Previous U.S. (Through 2003)	Current U.S. (2004-Current)
Workday Cycle	23 hours (15 on-duty/ 8 off-duty	24 hours (14 on-duty/ 10 off-duty	23 hours (15 on-duty/ 8 off-duty	24 hours (14 on-duty/ 10 off-duty
Maximum Driving Hrs Shift	13	13	10	11
Max. Daily * Driving Hrs	16	13	16	14
Max. Daily * Working Hrs	16	14	16	14
Min. daily * Off–duty Hrs	N/A	10	N/A	10
Elapsed Time Limit (Hrs)	N/A	16	N/A	14
Duty Cycles	3 (60 hrs/7 days) 70 hrs/8 days) 120 hrs/14 days	2 (70 hrs/7 days) 120 hrs/14 days)	2 (60 hrs/7 days) (70 hrs/ 8 days)	2 (60 hrs/7 days) (70 hrs/8 days)
Rest/Reset provision (hrs)	N/A	36 hrs or 72 hrs (Dependent on cycle)	N/A	34 hrs
Recording Method	Logbook (Electronic permitted)	Logbook (Electronic permitted)	Logbook (Electronic permitted)	Logbook (Electronic permitted)

Note: * Daily = 24-hour period [may include driving in two work shifts].

The Canadian rules shown in Table 1 apply south of the latitude of 60^{o}, which represents the vast majority of truck travel in Canada. As noted, the Canadian rules are slated for implementation early next year, whereas the U.S. rules are in effect now. In Canada, like the U.S., the standard daily required off-duty hours in the workday cycle have been increased from 8 to 10 hours. However, some features of the 10-hour off-duty requirement are different in Canada than in the U.S., as will be discussed below. Also, the provisions for two-up drivers are somewhat different than those for solo drivers. Otherwise, the provisions shown in the table are not sleeper berth-related, but are provided here as general information and background on the overall HOS rules.

A reality of North American transport regulation is that Canada often emulates the U.S. in its regulatory practices in the interest of harmonisation, competitiveness, and because of the overwhelming importance of U.S. trade for the Canadian economy. When the U.S. FMCSA proposed eliminating the split sleeper berth provision in its 2000 NPRM, Canada followed with a similar proposal. Later, when the U.S. reversed its plans and retained the split option, Canada also reversed their plans and retained the split. However, various features of the 10-hour off-duty period and required splits are different in Canada than the U.S.

Drivers not using truck sleeper berths must take 10 hours off-duty in a day, but only 8 of the hours need be consecutive. The other 2 hours can be distributed throughout the day in blocks of no less than 30 minutes. Solo drivers in trucks equipped with sleeper berths can split their 10 hours off duty into two periods, as long as each is at least 2 hours in duration. Two-up drivers using the sleeper berth can split their sleep as long as each off-duty period is at least 4 hours in duration and the total of the two periods is at least 8 hours. Two additional off-duty hours are required in a 24-hour period, but these can be obtained in separate non-sleeper berth periods of 30 minutes or more. A key difference, then, between the U.S. and Canadian split-sleep regulations for two-up drivers is that the U.S. now requires the two periods to be at least 8 and at least 2 hours, whereas the new Canadian regulations will require two periods of at least 4 hours as well as 2 additional hours that can be distributed across the work day.

Like the U.S., Canada has no regulations that discriminate between sleep in a moving vehicle versus a stationary one, or requiring that two-up drivers stop the vehicle periodically for stationary rest. In a personal communication, Mark Schauerte, Senior Policy Advisor for Motor Carrier Road Safety & Motor Vehicle Regulation at Transport Canada noted that there had been little discussion of such a requirement, and expressed the view that, although sleep in a moving vehicle may be inferior to that in a stationary vehicle, this may be related to personal factors such as the resting driver's confidence in the driver behind the wheel.

An expert panel conference on single driver split sleep was held by Transport Canada in late 2003 following the announcement of the U.S. rule that would continue to permit split sleep (and reversing its earlier proposal). The Canadian trucking industry had requested that split sleep be permitted, contrary to earlier plans to eliminate the split-sleep provision. A major rationale for the request was harmonisation between the countries, although other specific reasons were cited as well. The expert panel supported the industry request and recommended a split-sleep provision that was similar to that in the U.S. The panel noted that definitive research on the issue was lacking and that there were a number of outstanding research questions relating to sleeper berth use and split sleep. Panel deliberations were explicitly limited to single drivers and thus did not address issues relating to sleep in moving vehicles (Transport Canada, 2003).

3. RESEARCH FINDINGS AND OTHER CONSIDERATIONS RELATING TO THE SAFETY OF SLEEPER BERTH USE

This section summarises some major research findings and other considerations regarding the safety of two-up operations, with emphasis on the issue of sleep in a moving vehicle versus a stationary vehicle. First, several frequently cited North American studies on sleeper berth use are described. Next, aspects of two-up driving generally favourable to safety are summarised, followed by a similar summary of aspects generally unfavourable to safety. Research studies relating to these various factors are cited. In addition to factors clearly favourable or unfavourable to safety in two-up operations, other issues are problematic and do not lead to clear-cut conclusions; these are discussed also along with relevant research citations. Finally, the specific technical issue of quantification and evaluation of sleep in moving vehicles is addressed.

3.1 Major North American Studies Relating to Sleeper Berth Use

Much of the discussion relating to the safety of sleeper berth use in two-up operations is based on fragmentary or anecdotal findings, or on studies conducted in other settings such as laboratories. Under the sponsorship of FMCSA, VTTI has conducted the only one large-scale North American on-road study directly addressing sleeper berth use (Neale et al., 1998; Dingus et al., 2001; FMCSA, 2002). The methodology of this study is summarised below, and various findings are cited throughout this paper.

The VTTI study was a two-phase effort consisting of focus group discussions (Neale et al., 1998) and an on-road instrumented vehicle study under real operational conditions (Dingus et al., 2001). Focus groups were held in eight U.S. cities, and explored factors affecting the quality and quantity of sleep that drivers receive in sleeper berths, drivers' physical and mental fatigue while driving, and other safety issues associated with long-haul operations in which sleeper berths are used. A major, if unsurprising, finding was that many drivers reported that they did not sleep well in moving vehicles, in part because of the physical environment (vehicle motion, noise, poor ventilation and insulation) and in part because of unease with the other driver's driving safety or style. The success of two-up driving depended a lot on the relationship between the drivers; many of the most contented teams were married couples.

The instrumented vehicle phase of the VTTI study employed two trucks driven by 13 driver teams and 30 solo drivers, each for up to 10 days in normal long-haul operations. Unobtrusive vehicle instrumentation included video (including close-up view of the driver's face), vehicle dynamics (speed, steering, lane departure, braking, forward radar), and sensors to obtain sleeper berth environmental data. Dynamic vehicle data were analysed to identify "triggers" of potential critical incidents such as sharp lateral accelerations, hard braking, and short/fast closings with other vehicles. An Observer Rating of Drowsiness (ORD) scale was used to assess driver fatigue and identify extreme incidents. Drivers also completed sleep logs, subjective alertness ratings, and during sleep wore a Nightcap® sleep monitoring system.

Principal relevant results, also discussed as relevant elsewhere in this paper, included the following:

- The quantity and quality of sleep obtained in either a stationary or moving sleeper berth were lower than that obtained by drivers sleeping at home. This was particularly true for two-up drivers in moving trucks.
- Two-up drivers obtained more hours of sleep (about seven hours per day) than solo drivers (about six hours).
- Two-up driver sleep in moving vehicles was rated poorer in quality by drivers than solo sleep in stationary berths, and two-up drivers were more likely to be awakened during sleep in moving vehicles. The data on awakenings were based on both self-reports and Nightcap® recordings.
- Measured rapid eye movement (REM) time as measured by Nightcap® was lower in moving than stationary berths, but the validity of this finding is uncertain due to methodological questions.
- Two-up drivers had fewer instances of extreme drowsiness in critical incidents (one-fourth the number seen in solo drivers).

- Sharp individual differences were seen within each group. Four single drivers (of 56 total drivers) had more than half of the extreme drowsiness periods.
- Two-up drivers also tended to drive less aggressively than solo drivers, and had fewer critical incidents.
- Compared to solo drivers, two-up drivers tended to maintain more constant levels of alertness across the 24-hour day.
- Overall, two-up drivers were better able to manage their fatigue and safe driving practices to avoid high crash risk situations.

The Dingus et al. finding of overall higher alertness and safety in two-up driving compared to solo driving contradicted those of Feyer, Williamson, and Friswell (1997), who reported that two-up drivers showed more fatigue than solo driving in a similar between-groups comparison.

Findings relating to multiple days of driving and sleeping during a trip were somewhat mixed. Both two-up and solo drivers showed progressions toward deeper self-rated sleep during multi-day trips, probably reflecting cumulative fatigue. When 8-day trips involving two-up and solo drivers were compared, solo drivers were more likely to receive ORD ratings of “moderately to extremely drowsy” more often on Day 1, whereas two-up drivers were more likely to have these high ORD ratings on Day 8. In general, solo drivers were more likely than two-up drivers to be highly drowsy during the first half of the 8-day trips, whereas the opposite was true for the second half. But there were no strong, consistent parametric trends across the 8 days.

There are several methodological caveats relating to the VVTI sleeper berth study. Most notably, Nightcap® readings were obtained with “some difficulty” and may have been affected by vehicle motion. Of course, such confounding would tend to invalidate comparisons of sleep in moving versus stationary vehicles. The degree of this confounding is unknown. The Karolinska Sleepiness Scale was used to obtain self-ratings of alertness, but such ratings often do not correspond well to objective measures (Wylie et al., 1996, Dinges, 2005). Accordingly, subjective self-assessment data from this and other studies are not emphasized in this review. The ORD scale used to assess driver alertness during critical incidents is based on observer judgment, and thus can be subject to interrater bias and error. A final issue relates to the fact that ORD was assessed for critical incidents (generally reflecting traffic conflicts with other vehicles) but not for samples of non-incident driving. Most critical incidents reflect dynamic traffic interactions that are overwhelmingly related to driving behaviours (e.g., speeding, following too closely) or distraction as opposed to drowsiness (Olson et al., 2005). The large difference seen between solo and two-up drivers is the incidence of extreme drowsiness in incidents was likely a valid reflection of the overall incidence of extreme drowsiness, but this conclusion would be stronger if it had been corroborated by a comparison of randomly sampled time epochs controlled for certain variables known to affect alertness such as time-of-day, roadway type, and traffic density. In spite of these caveats, the VTTI study provides the most extensive and rigorous empirical evidence available on sleeper berth use and two-up driving safety in North America.

Another frequently cited study relating to sleeper berths was conducted by the IIHS (Hertz, 1988). IIHS used crash reports filed by carriers to the federal government to compare 418 crashes resulting in a truck driver fatality to 15,692 property damage-only (PDO) crashes. Fatal versus PDO crash differences in the incidence of various factors were considered to be indications of the fatal crash risk associated with the factors. Questions on the crash reporting form called for carriers to specify if sleeper berth had been split into two periods and whether the crash involved two-up or solo driving. Split sleeper berth sleep was associated with a 2.14-fold increase in fatal crash risk and two-up driving was associated with a 1.50-fold increase. The majority (79%) of fatal crashes involved solo rather than two-up drivers. When team status was controlled, the odds ratios for the split-sleep effect were found to be 2.02 for two-up drivers and 2.04 for solo drivers. When various situational, environmental, and operational factors were controlled, the association between split-sleep and fatality risk increased to about three-fold. No similar multi-factor analysis of two-up versus solo driving was reported. In regard to the question of sleep in moving vehicles, the author concluded that, "The fact that risk remained the same regardless of team status suggests that increased risk of fatality is associated with non-consecutive sleep rather than disturbance from the motion of the truck while sleeping." It should be noted also that the methodology of this study did not permit differentiation between two-up driver sleep in moving vehicles versus stationary vehicles or other locations.

The U.S. National Transportation Safety Board (NTSB) has conducted two major studies relating to driver fatigue and large truck crashes (NTSB, 1990; 1995). In the 1990 study, 182 fatal-to-the-driver large truck crashes were investigated. Driver fatigue was the most frequently cited principal cause of the crashes (31%), but no findings were cited regarding sleeper berth use or solo versus two-up driving. In the 1995 study, NTSB compared 62 fatigue-related single-vehicle tractor-trailer crashes to 45 such crashes that were not fatigue-related. Factors with the strongest association to fatigue crash involvement (compared to involvement in a non-fatigue crash) were duration of the most recent sleep period, the amount of sleep in the past 24 hours, and split sleep patterns. The fact that some of these factors were used in the study to classify crashes as fatigue or non-fatigue related raises the question of whether there was some circularity in the investigation and analysis methodology. Eight of the 62 fatigue-related crashes involved two-up operations compared to just one of the 45 non-fatigue-related crashes. However, these samples involved both long- and short-haul trips and all of the two-up vehicles were on long-haul trips. Thus, the confounding effects of long-haul versus short-haul driving and the small number of two-up cases prevent any strong conclusions from this study. Thus, the two NTSB studies, while widely cited in relation to the general issue of commercial driver fatigue and crash involvement, do not shed much light on the safety of two-up driving and sleep in moving vehicles.

The FMCSA Large Truck Crash Causation Study (LTCCS; Blower and Campbell, 2005) has collected extensive in-depth data on nearly 1,000 serious large truck crashes occurring prior to the 2003 HOS rule changes. This includes numerous variables relating to driver fatigue, HOS, and scheduling. Major top-level findings from the study have been widely reported. For example, Craft and Blower (2004) reported that of 589 large truck crashes (including both single- and multi-vehicle crashes) in a preliminary and unweighted LTCCS dataset, 40% had a "critical reason" assigned to the driver of the large truck. Of the 40%, the error type classifications were as follows: recognition errors (15%); decision errors (16%); performance error (4%); driver non-performance, including fatigue (4%); and unknown (1%). More detailed findings from the study have not yet been published, but release of the full data set is now imminent. When the data are released, they should provide important evidence pertinent to sleeper berth issues, including split sleep and sleep in a moving vehicle.

Note that all of the above studies were conducted prior to the 2003 rulemaking that required 10 hours off-duty rather than 8. This is a crucial consideration since 8 hours off-duty had been found to often result in only about 5 hours sleep (Wylie et al., 1996), and that such amounts may be considered sleep deprivation (Balkin et al., 2000). Findings from studies based on an 8-hour off-duty requirement may not generalise to today's situation in which 10 hours off-duty are required because the additional hours affords a much better opportunity for drivers to obtain sufficient sleep.

3.2 Factors Favourable to Safety in Two-up Operations

Considering the above research studies, other research, and various commentaries, positive aspects of two-up driving from the safety perspective can be summarised as follows:

- **Presence of a second person in the vehicle**. The presence of another person in the vehicle is a countermeasure to extreme sleepiness for at least two reasons. First, social interaction helps to sustain wakefulness (Dinges, 1995). Second, self-assessments of the level of fatigue and the probability of imminent loss-of-consciousness are often poor (Wylie et al., 1996, Itoi et al., 1993). The passenger in a vehicle may be a better judge of the driver's level of drowsiness than the driver himself or herself. Apart from fatigue, the presence of another person in the vehicle may inhibit unsafe behaviours such as speeding, tailgating, non-use of safety belts, and alcohol/drug use. Dingus et al. (2001) reported that two-up drivers in the VTTI sleeper berth study, in addition to having far fewer incidents with extreme fatigue, also drove less aggressively and made fewer driving errors than did solo drivers.

- **Sleep on demand.** Not only can a sleepy driver relinquish the wheel when desired, but also there is an available place to rest. In contrast, solo drivers may not be able to stop the truck due to schedule demands and, even if they are, there may not be a suitable place to park the truck (Chen et al., 2002). In North America, many public rest parking areas are full and overflowing at night, and many large trucks at these locations park illegally on shoulders or in other dangerous locations. Private truck stops generally do have spaces available, but many are not located in convenient locations and drivers are often reluctant to leave the main highway for a truck stop. Although many truck stops are excellent facilities, they may have their own set of problems, including noise from nearby idling vehicles (especially refrigerated vehicles), noise of vehicles entering or leaving the facility, pets or people talking, and occasionally nefarious activities like prostitution, drug dealing, and theft (Neale at al., 1998).

- **Greater regularity of sleep.** Although quantitative data are lacking, the fact that sleeper berth sleep is generally on demand for two-up drivers means that they can adopt more regular sleep schedules on long trips if they so choose. Solo drivers must look for a suitable place to park for both principal sleep periods and breaks, which adds to schedule variability, especially when parking spaces are not readily available. Mabbott et al. (2005) reported that two-up drivers who used regular 6-hour rotations between rest and driving exhibited less daytime drowsiness than those with less regular rotations. In its comments to the FMCSA rulemaking docket, the U.S. ATA (2005) asserted that American two-up driver generally strive to maintain regular 24-hour work and rest schedules by splitting their sleeper berth time by using regular 5-hour sleeper berth periods (although, as noted, a 2005 FMCSA rule change now requires an 8-hour principal period).

- **Reduced time-on-task.** Since two drivers can switch at almost any time, long driving periods are minimized and average driving time-on-task is reduced. Time-on-task is believed by many to be a major factor increasing fatigue crash risk (e.g., Park et al., 2005). In its Notice of Proposed Rulemaking, FMCSA (2000) cited data from the 1991-96 Trucks in Fatal Accidents file indicating that the risk of a fatal fatigue crash is strongly related to time-of-task, with relatively low risk for the first 6 hours and rapidly increasing risk for subsequent continuous driving hours. Other studies have yielded contrary results; for example, four major instrumented vehicle studies (Wylie et al., 1996, Dingus et al., 2001; Hanowski et al., 2005; Mabbott et al., 2005) have not seen large time-on-task effects on driver fatigue.

- **Greater overall sleep time**. In the VTTI sleeper berth study, Dingus et al. (2001) reported that two-up drivers obtained about one hour more sleep daily than did solo drivers. In a major laboratory study, overall sleep time was found to be a stronger predictor of daily alertness and performance than the duration of split-sleep periods (Maislin et al., 2001; cited in Rosekind, 2005). Note, however, that the current methodologies for assessing both the quantity and quality of sleep in moving vehicles are problematic. Some of these issues are discussed in a separate section below.

- **Possible alertness benefits from split sleep.** Although there is unquestionable value in long principal sleep periods with a full architecture of sleep stages, split sleep may have some benefits, at least for some people, given the same total amount of sleep. Two rationales for split sleep are the fact that sleep tends to be "front-loaded" in terms of its restorative benefits (Balkin et al., 2000) and that naps can boost alertness considerably (Trucking Research Institute, 1999, FMCSA, 2005). Transport Canada, in a 1998 review of "Options for Changes to Hours of Service for Commercial Vehicle Drivers," strongly supported napping for commercial drivers, stating that, ". . . a 2-hour nap is sufficient to promote and maintain recovery for an extended period" (Vespa et al, 1998). Given these conflicting considerations (i.e., "full architecture" vs. front-loading and nap benefits), this is an issue that needs to be resolved by further experimental research, both laboratory and in situ. Rosekind (2005) concludes that split sleep can provide equivalent restoration to longer continuous principal sleep periods as long as total sleep times are similar.

- **Lack of distractions and competing activities.** While mandatory daily off-duty periods are intended to be used primarily for sleep and personal hygiene, a number of studies have shown that drivers tend to engage in other competing activities that reduce the amount of sleep actually obtained (Wylie et al., 1996; Balkin et al., 2000; Morrow and Crum, 2004; Mabbott et al., 2005). Modern sleeper berths do provide various amenities (television sets, computers) that might also divert drivers from sleeping, but not to the same degree as truck stops or hotel rooms. There is an assumption that commercial drivers will focus their off-duty time on restorative activities, most importantly sleep, Morrow and Crum (2004) observed that, "drivers do not necessarily spend their non-work time in this manner."

- **Familiarity.** Although a truck sleeper berth is not optimal for sleep compared to a stationary bed, it does have the advantage of being a familiar environment. Rosekind (2005) notes that that there is a well-documented disruptive effect of unfamiliar environments (e.g. a new hotel room) in the first night of sleep.

- **Security.** Focus groups conducted as part of the VTTI sleeper berth study (Neale et al., 1998) stated that sleeping in a moving vehicle eliminated the security concerns sometimes associated with public rest parking areas and truck stops.

- **Continuously improving vehicle comfort.** Dramatic improvements have been made in heavy truck comfort over recent decades, and these improvements are continuing (U.S. ATA, 2005). Improvements include quieter engines, air ride suspensions (resulting in reduced vibration), improved heating and ventilation, smoother cornering, and smoother shifting through increasing numbers of trucks with automatic transmissions. Sleeper berths have become bigger and more commodious. Mabbott et al. (2005) noted effects of cab design on driver fatigue in their study, and it is likely that continuing sleeper berth and overall cab design improvements will positively affect driver alertness as these enhancements penetrate the vehicle fleet. Another implication of this consideration is that older studies relevant to sleeper berth use may have questionable relevance to the current situation because they were based on the inferior vehicle designs in use at the time.

- **Time and cost savings.** The primary purpose of two-up driving is of course to save transport time and associated costs. In addition, sleeping in a moving vehicle adds no additional cost to the transport operation, whereas stopping for sleep requires expenditures for a hotel room or, in most cases, fuel costs for idling the vehicle to provide ventilation and temperature control. The average fuel cost of idling was recently estimated at $3.00 U.S. (Tunnell and Dick, 2006), and prolonged idling also contributes significantly to engine wear.

3.3 Factors Unfavourable to Safety in Two-up Operations

Just as there are favourable aspects, there are clearly a number of negative aspects to two-up driving in regard to driver sleep, alertness, and overall motor transport safety. These include the following:

- **Poorer quality of sleep in moving vehicle.** The most important factor unfavourable to safety in two-up operations is the relatively poor quality of sleep in a moving vehicle in comparison to sleep in a stationary vehicle or in a bed. Dingus et al. (2001) found that sleep quality was lower for two-up drivers based on both self-ratings and on polysomnographic measures of sleep quality. In addition, two-up drivers were woken twice as frequently during sleep as were solo drivers in stationary berths. These empirical findings corroborated the qualitative findings of earlier focus groups (Neale et al., 1998). Major reasons for the relatively poor quality of sleep in the moving sleeper berth may include the following:
    - inherent disruption of sleep by vehicle motion;
    - noise or other disturbances of driving;
    - lack of confidence in the other driver's safety; and
    - annoyance and discomfort from both driving behaviours (e.g. hard braking) and non-driving behaviours of the driver (e.g., radio and mobile phone use, heat/air-conditioning).

It should be noted that stationary sleeper berths are not ideal sites for sleep either. As noted above, heavy vehicles generally must be left idling during rest periods to provide ventilation and temperature control, with some resulting noise and vibration. In most parking facilities there is noise from passing highway traffic and/or vehicles entering or leaving the facility.

- **Greater use of split sleep and shorter durations of principal sleep periods**. Two-up drivers are much more likely than solo drivers to split their sleep periods and thus have shorter principal sleep periods (Abrams, Schultz, and Wylie, 1997). Longer principal sleep periods permit deeper sleep and a fuller sleep architecture (FMCSA, 2005, Balkin et al., 2000) and, as discussed above, split sleep has been reported to be associated with an increased risk of serious crashes (Hertz, 1988). Rosekind (2005) advocates at least 6 hours principal sleep but, as discussed above, concludes that total daily sleep is a better predictor of alertness than whether sleep is split.

- **Possible greater fatigue at beginning of trip.** Prior to a trip, solo drivers are certain that they will be driving from the start, whereas two-up drivers may be uncertain if they have not coordinated driving plans with their partners in advance or been given specific despatching direction by their companies. In the absence of a specific plan, each driver of the team may tend to forego sleep in favour of home or recreational activities during their off-duty period, with the result that neither is fully prepared to drive when they report for duty. Feyer, Williamson, and Friswell (1997) reported that two-up drivers showed more evidence of fatigue before multi-day trips than did solo drivers. Proper training and management of two-up drivers can likely reduce this tendency but it may to some degree be inherent in the diffused responsibility of team operations.

- **Longer-term unhealthful effects.** Although definitive empirical research is generally lacking, probable longer term negative effects of sleep in moving vehicles include:
    - relative lack of exercise & physical activity;
    - possible reduced access to healthful foods;
    - cumulative effects of sustained vehicle vibration; and
    - perceived or real negative effects on personal hygiene and health from sharing sleeping quarters with another person (even if not sharing the berth at the same time).

- **Shorter rest stops**. Abrams, Schultz, and Wylie (1997) reported that two-up drivers tended to take somewhat shorter rest stops than solo drivers, although the difference (42 minutes versus 51 minutes on average) was not pronounced.

3.4 Problematic Aspects and Issues

Various other questions relating to fatigue in two-up operations have not been answered definitively. In regard to the overall safety of two-up versus solo operations, the most important "bottom line" question is whether two-up drivers are more or less alert and safe. Dingus et al. (2001) present contradictory evidence on this question. Two-up drivers rated themselves as drowsier than solo drivers on the Karolinska Sleepiness Scale, but no overall significant difference was found for ORD ratings in video reviews of triggered incidents. In the observer ratings, two-up drivers tended to show more moderate drowsiness, whereas solo drivers were more likely to be at the extremes; e.g."not drowsy" or "very/extremely drowsy." Solo drivers were more likely to be involved in critical driving incidents of all types, including those relating to HOS violations and extreme drowsiness. As noted, ORD ratings and objective alertness/performance measures for randomly selected periods of driving would have been a worthwhile supplement to the measures obtained for critical incidents. Mabbott et al. (2005) noted that two-up drivers in their study had a low incidence of extreme drowsiness, but their study did not directly compare two-up to solo operations.

Some driver teams, particularly married pairs, routinely stop the truck for 4-6 hours to obtain better quality sleep, even though this is not required by any North American regulation, and not known to be required by many trucking companies. Indeed, surprising survey statistics have been cited on the percent of team drivers taking their sleep in moving vehicles. In the 2003 HOS Final Rule, FMCSA cited a 1997 ATA survey reporting that only five percent of two-up drivers use the sleeper berth while the vehicle is in motion, and an OOIDA survey reporting a percentage of 11 percent. These percentages seem implausibly low given that a major rationale for two-up driving is to keep the truck moving, and given discussions in the rulemakings (e.g., FMCSA, 2005) that two-up drivers prefer regular even splits during long-haul driving.

Non-married driver teams may be much less inclined to stop the vehicle for sleep in the berth due to the other driver's snoring, other annoying habits, or simply not wanting to sleep in close confines with another person. Few North American driver teams – especially non-married teams--stop at hotels for extended sleep and rest outside the truck (Abrams, Schultz, and Wylie, 1997). Factors mediating against team driver use of hotels include cost, parking restrictions and limitations, security, and time added to the overall trip. Unmarried team drivers may choose to stay at a truck stop or hotel when both drivers are forced to stop work for a longer time period because weekly work hour limits have been reached. Currently, this might be the 34-hour period required for restart. But a major rationale for two-up driving is to reduce this likelihood and, even if both drivers needed a restart period, the two periods would not overlap entirely and thus the required period of vehicle stoppage would be less than 34 hours.

Driver teams choosing to stop the truck for rest in a stationary vehicle are likely to do so because of pronounced fatigue, to avoid heavy traffic (e.g. to wait until rush hour traffic has dissipated), or because they have arrived at a pick-up or delivery location and are waiting to load or unload the vehicle. Extreme fatigue is most likely to occur during the deep circadian trough in the overnight hours between midnight and dawn. Sleep is likely to be deepest and most restorative during these hours, and driving during these hours has the highest driver fatigue risk (Dinges, 1995; Wylie et al., 1996).

Dingus et al. (2001) reported that two-up drivers were more alert during night driving (based on ORD) than were solo drivers. Although night driving is clearly associated with an overall increased risk of fatigue, it is questionable whether it is more hazardous overall when all types of crash risk are considered, at least in the U.S. Hendrix (2002) calculated total fatal crash rates by hour-of-day in four U.S. states based on crash records and time-stamped traffic volume counts. The overall fatal crash rates for combination-unit trucks were roughly constant across the 24-hour day, in contrast to the passenger rate which was greatly elevated in the overnight hours. Because relatively more fatal crashes than non-fatal crashes occur during the overnight hours, this finding implies (albeit it did not demonstrate) that the non-fatal large truck crash was actually lower in the overnight hours than during daytime. In an instrumented vehicle study of long-haul trucking operations, Knipling et al. (2005) compared the hourly distribution of traffic conflicts to a control exposure measure (the distribution of randomly selected time epochs) and found that the overnight hours were associated with greatly decreased incident risk compared to the rest of the 24-hour day (especially afternoon rush hour). An implication of these studies is that restrictions on overnight driving designed to reduce fatigue risk may not have "bottom line" safety benefits when all traffic crash risks are considered, especially in heavily populated areas where most large truck crashes and incidents are associated with the vagaries of car-truck interaction in traffic as opposed to loss of alertness by truck drivers. The Mabbott et al. (2005) finding that two-up driver alertness (as measured by the ARRB

Fatigue Monitoring Device) was actually greater during night time than during daytime further complicates this picture and reinforces the point that the human circadian rhythm is not necessarily the dominant force in determining overall driver safety performance.

Given that two-up drivers can legally drive almost twice as many hours and kilometres in the same time period over multiple days, one would think that two-up drivers are subject to less time pressure from delivery schedules. Beilock (1995) reported that "Solo drivers were more likely than team drivers to have tight schedules." However, a contradictory finding was reported by Abrams, Schultz, and Wylie (1997), who found in their survey that two-up drivers were somewhat more likely than solo drivers to report that they did without sufficient sleep to meet delivery deadlines and other operational demands.

A number of authors have noted that some drivers are much more suited to two-up driving than others, and that selection of drivers suited for two-up driving should be a focus of carriers' efforts to manage driver fatigue. In part, this should be a facilitation of self-selection – that is, drivers themselves should consider what's involved in two-up operations, whether they are suited to it, and whether they are comfortable with their perspective partners. Each driver as well as the company should be comfortable with a decision to embark on long two-up trips.

Although the evidence for individual differences in driver suitability for two-up driving is more qualitative than quantitative, there is strong quantitative evidence of pronounced and enduring individual differences in general susceptibility to fatigue. In the Driver Fatigue and Alertness Study (Wylie et al., 1996), 14% of the drivers in the study were associated with 54% of the observed drowsiness episodes. Knipling (2005) reviewed several instrumented vehicle studies involving both commercial and non-commercial drivers and found similar, or even more extreme, differential fatigue risk among drivers. Experimental sleep deprivations studies (e.g. Van Dongen et al., 2004) demonstrate similar findings. Moreover, they show that inter-individual differences are enduring, and thus may be regarded as human traits. While these empirical findings do not relate specifically to two-up driving, they reinforce the view that humans vary considerably in sleep and alertness patterns and that driver selection is a critical step in fatigue management at the carrier level. As this research is advanced in coming years, quantitative data may be forthcoming on drivers' ability to sustain alertness in two-up operations and on associated physiological and behavioural characteristics. A broad implication of research on individual differences in fatigue susceptibility may be that constitutional characteristics of individual drivers are just as important as situational determinants of alertness such as driving schedule.

3.5 Sleep and Alertness Assessment in Moving Vehicles

An important caveat regarding many of the studies cited in this paper is that there are significant methodological limitations in measuring sleep quantity and quality in moving vehicles. Two methods of objective assessment are polysomnography (PSG) and actigraphy. PSG continuously monitors several types of physiological activity during sleep, including brainwave activity (electroencephalography or EEG), eye movements, muscle tone (e.g. arms, legs), breathing, heart rate, airflow, and oxygen saturations. Actigraphy is a record of body movement from which calculations can be performed to obtain sleep quantity and quality.

Full PSG measurement including EEG is the most accurate way to assess sleep, but such instrumentation suites are expensive and generally require a technician to position electrodes and otherwise attach and monitor the system. A cap can be used provide a guide for electrode placement and stability, but a conducting scalp cream is needed for best results. Even with good electrode placement and full conductivity, there is some question regarding the robustness of EEG measurement in moving vehicles. Dingus et al. (2001) used the Nightcap® EEG monitoring system in their sleeper berth study, and reported that rapid eye movement (REM) sleep was reduced during sleep in moving vehicles compared to stationary, but noted that the validity of this result may have been affected by vibration of the measurement system. On the other hand, PSG/EEG measurement has been used successfully in airplanes (Signal et al., 2003) and, in a recent personal communication, Thomas Balkin of the U.S. Walter Reed Army Research Institute expressed the view that PSG/EEG measurement could be reliable in moving motor vehicles.

Actigraphy has now been used extensively for sleep and fatigue related studies where ambulatory measures are needed (e.g. Balkin et al., 2000), and measurements of both quantity and quality of sleep can be derived from the activity data obtained. The accuracy of actigraphy is degraded in moving vehicles, although Mabbott et al. (2005) did report meaningful sleep-alertness findings based on actigraph data recorded in moving vehicles. Refinement of actigraphy for use in moving vehicles is a research need for addressing the sleeper berth issue. One possible but unproven approach would be to employ an unattached "control" actigraph in the sleeper berth to measure ambient vibration, which could be subtracted from the human actigraph data (Martin Bruner, Ambulatory Monitoring, Inc., personal communication, 2006).

Non-technological methods of assessing quantity include sleep logs and subjective ratings. For example, Dingus et al. (2001) used a wake-up survey to obtain data on hours slept and subjective self-ratings of sleep quality. Based on driver self-rating scales, Dingus et al. (2001) reported that sleep was of somewhat lower quality for two-up drivers on the road than at home, and also somewhat lower quality than the on-the-road sleep of solo drivers who slept in stationary vehicles.

In contrast, measurement techniques for assessing driver alertness and performance while driving are at present more robust and reliable than those for assessing sleep quality in moving vehicles. Lane tracking measures (e.g. standard deviation of lane position) are also well-established as assessments of driver alertness or impairment (Dinges et al., 2005). PERCLOS, a measure of eye closure, has a strong scientific basis (Wierwille, 1999; Dinges et al., 1998) but current technologies in use have not been highly reliable. The Psychomotor Vigilance Test (PVT) is a very reliable measure of alertness (Dinges et al., 1998; 2005) but cannot be administered during the driving task. ORD is readily obtained from videos of drivers' faces and has moderate interrater reliability. Together, these and other driving alertness measures currently offer better potential measures of driver alertness and performance during driving than the potential measures of sleep quality in moving vehicles discussed above.

The ARRB Fatigue Monitoring Device (FMD) employed in the recent NTC-sponsored two-up policy development study (Mabbott et al., 2005) appears to be a promising approach to measuring driver fatigue during transport operations. From the description provided in the report, the FMD likely taps similar psychomotor abilities and states as the PVT but, unlike the PVT, it can be administered during highway driving. One concern regarding FMD validity addressed in the study was that of potential confounding from stimulus visibility under different light conditions in the cab.

One type of driver alertness assessment that has often not provided robust measurements is the subjective self-assessment. Various studies, including the FHWA Driver Fatigue and Alertness Study (Wylie et al., 1996) and studies reviewed by Dinges (2005) have shown that subjective self-assessments often do not correspond well to objective assessments. Accordingly, self-assessment data have not been emphasised in this paper.

4. IMPLICATIONS FOR FLEET MANAGEMENT OF FATIGUE IN TWO-UP OPERATIONS

Because of methodological issues and some contradictory findings, current research does not provide a categorical answer to the question of whether two-up operations ultimately support or degrade driver alertness compared to solo operations. Nevertheless, there are several clear implications for carrier fatigue management practices. Most fundamentally, long-haul two-up driving is not for everybody. In focus group discussions, drivers tended to express extreme views on two-up driving – they either loved it or hated it (Neale et al., 1998). Those who liked it said that they trusted their partner and had no trouble sleeping in a moving truck. Many of these drivers were members of husband-and-wife teams and were happy with their living and working arrangements. In contrast, drivers who did not like two-up driving stated that they did not sleep well in the moving truck, often due in part to a lack of full confidence in the safety of their co-driver. Sometimes the complaint focused more on the co-driver's inability to drive smoothly than on safety. In addition to driving safely and smoothly, the driver behind the wheel needs to be considerate of the other driver in regard to radio loudness, cell phone conversations, other noise, and heating/air-conditioning. Some of the personal countermeasures that solo drivers use against drowsiness such as loud music, singing, and opening windows are disruptive to the sleep of the driver in the berth.

Because of the above personal sensitivities and individual differences, companies should carefully select drivers for two-up driving. They should ensure that teams are personally compatible, trust each other's driving, and are comfortable with each other's driving styles. They should also ensure that each driver is ready and able to adapt to the two-up driving routine. Henderson (1990; cited in NTC, 2006) noted that, "The least safe conditions would be associated with drivers who are badly adapted to the two-up system and to taking their rest in comparatively short segments, and who cannot rest in a moving vehicle. It is likely that such drivers never safely operate two-up."

In addition to a need for better selection of drivers for two-up operations, there is a need for driver training addressing fatigue management in general but also focusing on issues specific to two-up driving. Training topics specific to two-up driving include trip preparation (e.g. coordinating off-duty schedules so that one driver comes ready to drive), optimal rotational schemes, telltale signs of fatigue in one's self and one's partner, and consideration for the other driver's sleep needs and quality. Conducting such training prior to two-up assignments may be a way for fleet safety managers to assess drivers' suitability for two-up driving.

A specific despatching practice for two-up driving should be to identify which driver will begin the next trip prior to the weekend off-duty period. This would address the possible tendency of two-up drivers to report for duty less rested than solo drivers. As stated by Feyer, Williamson, and Friswell (1997), "effective management of fatigue involves considerations of the whole pattern and timing of work and rest."

Finally, safety managers should get as much feedback as possible to evaluate drivers' adaptation to two-up driving, just as they would any other aspect of driver safety. Managers should ask each driver about safe driving practices during trips and specifically whether they are able to obtain sufficient quality sleep. A driver with complaints about sleep quality, rotational schedules, their partner's driving, or other safety-related aspects of two-up trips is likely to be at-risk in future trips if the issues are not resolved. Some drivers may be hesitant to disparage their partners but others may readily reveal fatigue-related or other safety concerns that can be addressed by the safety manager. In extreme cases, a driver may correctly identify his or her partner as being among the most fatigue-prone drivers who constitute a disproportionate safety risk to themselves, their companies, and the public.

Companies employing a systematic, proactive, and safety-oriented approach appear most likely to have good safety and operational outcomes from two-up driving. In contrast, companies that despatch drivers to two-up trips on an ad hoc basis without preparation or focused management seem likely to encounter safety and/or driver acceptance problems. Two-up driving is a specialised transport operation and should be approached as such by companies employing it.

5. SUMMARY AND CONCLUSIONS

This paper has reviewed two-up (team) commercial driving regulations in the U.S. and Canada and summarised the operational and safety considerations associated with sleeper berth use in two-up operations. Studies relevant to two-up driving have often focused on the issue of split-sleep periods since two-up drivers are likely to manage their sleep and rest using split sleep. While sleep obtained in sleeper berths of moving vehicles is widely regarded as inferior to that obtained in stationary vehicles or in a bed, there are methodological issues in scientifically evaluating sleep in moving vehicles and, more importantly, factors at play in sleeper berth use that go beyond the physical sleeping environment. Instead, a full consideration of the issue must also consider social and operational factors that affect driver sleep habits and preferences. Two on road studies, the VTTI sleeper berth study in the U.S. (Dingus et al., 2001) and the recent NTC-sponsored two-up study (Mabbott et al., 2005), have shown that two-up operations can support high overall driver alertness and safety, although a third study (Feyer, Williamson, and Friswell, 1997) was less favourable.

Neither the U.S. nor Canada has implemented nor seriously considered regulations differentiating between sleep in moving vehicles versus stationary sleep, and in the U.S. no regulations apply exclusively to two-up drivers. Were proposals advanced in the U.S. or Canada to require two-up drivers to periodically stop the vehicle for stationary rest, proponents would likely cite the greater quality and restorative value of sleep at stationary locations (Dingus et al., 2001), whereas opponents would likely cite the overall safety of two-up driving (Hertz, 1990; Dingus et al., 2001; Mabbott et al., 2005) and various practical and operational difficulties caused by requiring such a stop. Unmarried teams in particular would likely object to a requirement that they stop the truck for sleep together in the berth. Any unintended shift away from two-up operations and toward solo operations resulting from such a regulatory requirement would probably detract from any safety gains from the requirement. In his March 2005 paper, Rosekind (2005) concluded that, given these conflicting considerations, insufficient data exist to resolve the question of whether two-up driver sleep in moving vehicles sustains equivalent levels of alertness and performance to that obtained in other environments. This review concurs with that assessment.

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