Masthead Logo

Journal of Transportation Management

Volume 21 | Issue 2 Article 6

10-1-2009

The impact of hours-of-service regulations on transportation productivity and safety: A summary of findings from the literature

Hokey Min

Bowling Green State University, hmin@bgsu.edu

THE IMPACT OF HOURS-OF-SERVICE REGULATIONS ON TRANSPORTATION PRODUCTIVITY AND SAFETY: A SUMMARY OF FINDINGS FROM THE LITERATURE

Hokey Min

ABSTRACT

Since driver fatigue has known to be the primary cause of serious truck crashes, the Federal Motor Carrier Safety Administration (FMCSA) has attempted to implement new hours-of-service (HOS) regulations that aimed to promote safer driving environments. The new HOS regulations effective on October 1st of 2005, however, may lead to substantial cost increases for the trucking industry which will in turn hurt shippers and ultimately customers. For instance, motor carriers may need to hire additional drivers to comply with new HOS regulations requiring that drivers be placed out-of-service until they accumulated enough off-duty time. In particular, off-duty breaks required to refresh driving hours were increased to 10 consecutive hours from the old rule of eight cumulative hours. A chronic shortage of truck drivers coupled with new HOS regulations could further aggravate the driver recruitment and retention problems. In addition, due to potential loading/unloading delays and stiffer fines/penalties resulting from new HOS regulations, trucking productivity may decline. To help trucking firms cope with various challenges of new HOS regulations, this paper provides a systematic overview of prior literature that examines the impact of HOS on transportation productivity and safety in the U.S. It also discusses managerial implications of new HOS regulations.

INTRODUCTION

The hours of service (HOS) regulations were first introduced by the now-abolished Interstate Commerce Commission (ICC) in 1937 as a way to protect the safety of long-haul truckers. The HOS's main purpose is to prevent truck accidents caused by driver fatigue. This is accomplished by limiting the number of driver working hours per day and week. Driver working hours include the time spent on loading, unloading, driving, handling freight, preparing reports, preparing vehicles for service, or performing any other duty pertaining to the transportation of passengers or property. The main reason for limiting driver working hours is to prevent fatigue by keeping drivers on a 21- to 24-hour schedule, maintaining a human body's natural sleep and wake cycle (so-called circadian rhythm). Drivers are required to take a daily minimum period of rest and are allowed longer weekend rest periods to combat sleep deprivation, cumulative fatigue, and time-on-task fatigue effects that accrue on a weekly basis (Federal Motor Carrier Safety Administration, 2006). Despite their intent to enhance traffic safety, HOS regulations have become sources of controversy because it is hard for the policy maker to determine exactly how long drivers should work and sleep for their safety. As such, there were numerous proposals to amend HOS regulations between 1962 and 2009, but none were ever finalized due to contentious debates over their effectiveness in enhancing traffic safety.

One of the most notable proposals of those includes the highway reauthorization bill recently passed by the U.S. House of Representatives, which contained several important amendments for HOS regulations that aimed to balance the requirement for highway safety and the need for effective trucking services in the United States. Amended HOS regulations introduced by the U.S. Federal Motor Carrier Safety Administration (FMCSA) in 2003 and 2005 were generally well received by drivers, carriers, and shippers, although carriers seek more flexible sleeper berth rules. The main theme of the 2003 HOS rules is to increase an opportunity for restorative sleep by increasing the amount of off-duty time by two hours. To elaborate, these rules allowed truck drivers to drive a maximum of 11 hours after 10 consecutive hours off duty. However, truck drivers are prohibited to drive beyond the 14th hour after coming off duty, following 10 consecutive hours of duty. The 2003 HOS rules were further refined in 2005 which remained virtually unchanged as of 2008, because of a decision by the United States Court of Appeals for the District of Columbia Circuit in *Public Citizen et al. versus Federal Motor Carrier Safety Administration* (374 F.3d 1209) on July 16, 2005, which stated the 2003 HOS rules did not consider the impact of rules on driver health (Blanchard, 2004). As summarized in Table 1, the 2008 HOS rules intended to increase potential for quality sleep by mandating commercial motor vehicle (CMV) drivers to take at least 8 consecutive hours in the sleeper berth plus two consecutive hours either in the sleeper berth, off duty, or any combination of the two.

Unfortunately, these amended regulations were still attacked by the International Brotherhood of Teamsters and public safety advocacy groups such as *Public Citizen, Parents against Tired Truckers (PATT), and Citizens for Reliable and Safe Highways (CRASH)* despite the fact that truck crashes and driver fatalities have fallen in the recent years even as more freight has been moved since their enactment (Cutler and Regan, 2007). To elaborate, the 2006 fatal crash rate for large trucks stood at 1.93 fatal crashes per 100 million vehicle-miles-traveled. This rate broke the previous low of 1.97 fatal crashes per 100 million vehicle-miles-traveled in 2002. The large truck-involvement rate fell to 2.12 per 100 million vehicle miles traveled, down from 2.21 a year earlier. The fatality rate declined to 2.24 per 100 million vehicle-miles-traveled, down from 2.34 in 2005 (Business Wire, 2008).

So, the fundamental questions still remain to be answered:

(1) Do these amended HOS rules save lives, or do they put more lives at risk?

(2) Do these amended HOS rules improve carrier operations and subsequently enhance trucking productivity or do they put the trucking industry in jeopardy and thus increase trucking business failures?

Since the major goals of various interest groups are varied and often conflicting, the implications of HOS regulations have become one of the most controversial topics in the United States. Those groups, such as shippers, who are in favor of 2008 HOS rules have advocated maintaining status quo or getting the 2008 HOS rules legislated into law, without FMCSA ever addressing the above questions. On the other hand, those groups, such as public safety advocacy groups, who are opposed to the 2008 HOS rules have supported enacting stricter controls over the trucking industry on the premise that drivers who are allowed more than 10 hours a day behind a wheel will get fatigued and threaten the safety of the general public on the road. Recognizing these contrasting views and interpretations of the HOS rules, this paper intends to gather factual evidence from the past scientific studies regarding the HOS rules and their related issues such as human fatigue, circadian rhythms, accident rates, fatalities, potential carrier costs, and trucking productivity and then validate some of the rationale behind arguments made by various interest groups. Specifically, the main objectives of this paper are to

1. Synthesize the existing literature dealing with the pros and cons of HOS rules with respect to their safety and productivity implications;

2. Identify key factors influencing driver fatigue, reduced alertness, and driving task performance based on the findings of the past studies;

3. Clarify the myth surrounding the correlation between HOS rules and transportation safety and trucking business failures based on secondary data analyses;

4. Recommend best-practices and more productive transportation strategies that can minimize driver fatigue and improve driver productivity under new HOS rules;

5. Discuss the future outlook for extensions of existing HOS literature and untapped research topics relevant to HOS rules.

TABLE 1
RECENT CHANGES IN HOURS-OF-SERVICE RULES

2003 HOS Rule Property Carrying CMV Drivers - Compliance Through 09/2005	2008 HOS Rule Property Carrying CMV Drivers Compliance On & After 01/19/2009
May drive a maximum of 11 hours after 10 consecutive hours off duty.	No Change
May not drive beyond the 14th hour after coming off duty, following 10 consecutive hours off duty.	No Change
May not drive after 60 hours of duty in 7 consecutive days if the employing motor carrier does not operate commercial motor vehicles every day of the week. • A driver may restart a 7 consecutive day period after taking 34 or more consecutive hours off duty.	No Change
May not drive after 70 hours of duty in 8 consecutive days if the employing motor carrier operates commercial motor vehicles every day of the week. • A driver may restart a 8 consecutive day period after taking 34 or more consecutive hours off duty.	No Change
May not drive after the 14th hour after coming on duty 5 days a week or after the 16th hour after coming on duty 2 days a week for those drivers who operate within a 150-mile radius of their normal work reporting location.	No Change
Commercial motor vehicle (CMV) drivers using a sleeper berth must take 10 hours off duty, but may split sleeper berth tome into two periods provided neither is less than 2 hours.	CMV drivers using the sleeper berth provision must take at least 8 consecutive hours in the sleeper berth, plus 2 consecutive hours either in the sleeper berth, off duty, or any combination of the two.

Note: Passenger-carrying carrier/drivers are not subject to the above rules. These operations must comply with the hours-of-service limitations in 49 CFR 395.5.

KEY HOS PREMISES AND THEIR RATIONALE

The human body typically functions on a 24-hour cycle. To elaborate, most people's biological clocks work on a 25-hour cycle rather than a 24-hour cycle. However, the human body's biological cycle normally follows the 24-hour cycle of the sun rather than the human body' innate cycle, because sunlight or other bright lights can reset a pair of pinhead-sized brain structures called suprachiasmatic nucleus (SCN) that contain about 20,000 neurons (Koukkari and Sothern, 2006). This biological clock is set based on circadian rhythms which dictate changes in the human's mental and physical characteristics in the course of a day. These changes include: fluctuations in blood pressure, heart rate, body temperature, hormones, memory, reaction time, and attention span. Thus, circadian rhythms influence total sleep hours, rest hours, and subsequent restoration power of the human body (Liskowsky, 1992).

In particular, the disruption of circadian rhythms caused by irregular work patterns and sleep deprivation that are common in long-haul truck

driving can lead to serious driver fatigue and performance decrement (Ogilvie and Wilkinson, 1984). The cumulative driver fatigue would increase the likelihood of the driver's slow reaction, slow driving, disorientation, poor gear change, poor steering, and lane deviation and thus increase the risk of truck crashes (Office of Technology Assessment, 1991). As a matter of fact, a number of studies linked driver fatigue to safety. For example, Van Cauter and Turek (1990) observed that driver fatigue tended to deteriorate driving performance and subsequently increased accident rates. Similar conclusions were drawn by Sweedler et al. (1990) and Mitler et al. (1997) whose studies indicated that fatigue was one of the most probable causes of many truck crashes in the United States. Indeed, the U.S. National Transportation Safety Board (2008) blamed driver fatigue as a probable factor in 20-40% of truck crashes. That is to say, when truck drivers become fatigued from excessive driving/working hours and continuous sleep deprivation (e.g., sleep apnoea, insomnia, narcolepsy), they significantly increase the risk of truck crashes that result in fatalities and serious injuries. Considering this serious risk to public safety, HOS's main intent is to provide an increased opportunity for truck drivers to obtain necessary rest and restorative sleep. This intent of HOS, however, is in conflict with the goal of many truck drivers whose earnings depend heavily on the number of their driving hours. The U.S. National Transportation Safety Board (2008) estimated that the average trucker drove 125,000 miles a year, and that was on the low end of an average. The question remains how one can compromise the number of driving hours sufficient enough for truckers to make their ends meet, while not too long for them to lose their circadian rhythms and necessary daily sleeps.

An answer to the above question hinges on the threshold of sleep deprivation that can adversely affect driving performance and begin to pose a serious danger to both truck drivers and others on the road. One of the clues can be found in several recent studies that examined the impact of partial and full sleep deprivation on driving impairment such as lane keeping performances. These studies include Fairclough and Graham (1999) who discovered that the effect of one night sleep deprivation was equivalent to that of 0.07% blood alcohol content (BAC). Similarly, Arnedt et al. (2001) found that the impact of 21 hours of driving without any sleep on driving performance was equivalent to that of 0.08% of BAC. Driving with such a level of BAC is illegal in most of the U.S. since that level of BAC would increase the risk of fatal vehicle crashes by three to 17 times more (Heng et al., 2006). Amundsen and Sagberg (2003) also discovered that even a small reduction in sleep (e.g., restricting sleep less than seven hours) could triple the accident risk. Considering such risk, 2003 HOS aimed to move towards a 24-hour work-rest cycle, enhance the opportunity for restorative sleep by increasing the amount of off-duty time by two hours, and strike a balance between uniform, consistent enforcement, and operational flexibility. As shown in Table 2, Federal Motor Carrier Safety Administration (FMCSA) under the U.S. Department of Transportation (2003) estimated that 2003 HOS would save up to 75 lives and prevent as many as 1,326 fatigue-related crashes annually (http://www.fmcsa.dot.gov/about/news/news-releases/2003/052703.asp).

Taking a step further, new 2008 HOS rules effective on January 19th of 2009 require 10 consecutive hours of off-duty time to increase the potential for quality sleep. However, the new HOS rules may lead to substantial cost increases for the trucking industry which will in turn hurt shippers and ultimately customers. For instance, the trucking industry may need to hire additional 84,000 drivers to comply with the new HOS rules requiring that drivers be placed out-of-service until they accumulated enough off-duty time. In particular, off-duty breaks required to refresh driving hours were increased to 10 consecutive hours from the old rule of eight consecutive hours. A chronic shortage of truck drivers coupled with the new HOS rules could further aggravate the driver recruitment and retention problem. In addition, due to potential loading/unloading delays and stiffer fines/penalties (between $550 and $11,000 per violation depending on the severity) imposed by the new HOS rules, motor carriers such as Schneider National estimated that trucking productivity would decline by 4-19% (WERC, 2004). Similarly, the new HOS rules stipulated that drivers would be considered on duty when loading and unloading or waiting to clear customary paperwork. For this reason, most observers anticipate significant productivity losses--in some cases approaching 20%--particularly for truckload carriers. As such, Wal-Mart expected the new HOS rules to add $25 million to the cost of new drivers and tractors alone (Clair and Fox, 2004). Furthermore, a HOS compliance cost can add a significant burden to the trucking industry. For example, the purchase and installation of an electronic on-board recorder (EOBR) could cost the trucker more than $2,000. Its annual operating and maintenance cost of $200 should be factored into the cost estimate as well. Also, drivers averaged 20 minutes of time to write logs for each trip and fleet managers typically spent 20 minutes a month to review and monitor

TABLE 2
TRAFFIC SAFETY RECORD AND HOS EFFECTS FOR LARGE TRUCKS (GROSS VEHICLE WEIGHT RATING EXCEEDING 10,000 POUNDS)

2001-2003 total number of large truck involved in crashes	141,000 crashes
2001-2003 total number of large truck involved in fatigue-related crashes	18,000 crashes
1997-2000 average fatalities in fatigue-related crashes	375 people
1997-2000 average injuries in fatigue-related crashes	7,500 people
1997-1999 average cost per truck crash	$62,613
2002 total cost of fatigue-related crashes	$2.3 billion
Lives that could have been saved in 2002 by 100% HOS compliance	75 to 120 people
Estimated annual cost savings to motor carriers by 100% HOS compliance	$900 million to $1.3 billion
Net benefits of HOS rules	**$600 million to $1.1 billion per year**

Source: FMCSA (2005), Commercial Motor Vehicle Facts, http://www.truckbrakesafety.com/pdf/articles/fmcsa-facts-figures.pdf; FMCSA (2008), *The Large Truck Crash Causation Study*, http://www.fmcsa.dot.gov/facts-research/research-technology/analysis/FMCSA-RRA-07-017.htm.

driver compliances; thus, HOS compliance efforts would be detrimental to trucking productivity (Barnes, 2000). Complicating the HOS compliance efforts, new HOS rules can be interpreted in many different ways since FMCSA officials have no plans to issue a clarification to the rules (Adams, 2005). For example, the rules do not regulate how off duty hours must be used, how a mandatory two rest-break should be utilized, and what the parameters of a continuous 14 shift should be. Thus, many drivers may end up taking odd nap times, trying to travel hundreds of miles without a proper rest-break, and feeling the increased pressure of meeting delivery times.

THE DRIVER FATIGUE MODEL

As discussed earlier, the leading cause of truck accidents is driver fatigue. In fact, driver fatigue was the primary cause of 2% to 23% of all truck crashes (O'Hanlon 1978, Horne and Reyner, 1995). Reissmann (1997) also discovered that drowsy drivers were responsible for 50% of the fatal vehicle crashes on the Pennsylvania Turnpike and New York Thruway. In particular, driver fatigue is overrepresented in accidents during nighttime, single-vehicle accidents, high-speed (especially more than 90 miles) accidents, and accidents on monotonous roads (Sagberg, 1999; Amundsen and Sagberg, 2003). A recent study conducted by the Adelaide Centre for Sleep Research showed that drivers who have been awake for 24 hours have an equivalent driving performance to a person who has a BAC (blood alcohol content) of 0.1 g/100ml are seven times more likely to have an accident (http://www.smartmotorist.com/traffic-and-safety-guideline/driver-fatigue-is-an-important-cause-of-road-crashes.html, 2008).

The typical symptoms of driver fatigue include groggy and exhaustive feeling, frequent yawning, strained eyes, daydreaming while on the road, driving right of center, driving with varying speed, and experiencing short bursts of microsleep (i.e., a lapse from wake to sleep that lasts only a few seconds). One of the ironies of driver fatigue is that the driver may be too tired to determine his/her own level of fatigue (http://www.sleep-deprivation.com/articles/causes-of-sleep-deprivation/driver-fatigue.php, 2008). Since driver fatigue reduces driver alertness and adversely

affects driver performance, it has been the central theme of the various HOS rules. Thus, it is important for us to understand what causes driver fatigue and how significantly driver fatigue influences truck safety. To increase such understanding, we developed a driver fatigue model based on the findings of prior studies and theory postulated by human biology and behavioral science.

Factors Influencing Driver Fatigue

Driver fatigue is affected by a multitude of factors encompassing human biology (e.g., circadian rhythms), working environments (e.g., time on the road), working schedules (e.g., trip schedules), and work demand (e.g., breaks). Among those factors, a circadian rhythm is generally known to be one of the most important factors contributing to driver fatigue since it directly affects a driver's psychological processes and mental functions such as memory, reaction time, manual dexterity, and feel of alertness that, in turn, influence driver performance (Office of Technology Assessment, 1991; Dawson et al., 2001; Fletcher and Dawson, 2001). Figure 1 shows how driver fatigue can increase the risk of truck crashes. To complicate the driver fatigue model, the circadian rhythm is intertwined with a driver's individual characteristics (e.g., age, fitness, driving experience, sleep disorders, medical conditions), monotonous working environments creating boredom (e.g., straight driving with a lack of stimulation), and work schedules (e.g., nighttime driving, long working hours, cumulative sleep debt, irregular rest periods) (Brown, 1993; Crum et al., 2001; Eskandarian, 2007). Figure 2 displays the correlation between these attributes and driver fatigue. In the next sub-sections, we will elaborate on the effect of some of these factors on driver performance and subsequent truck safety.

Driver age. It is a common perception that younger drivers are likely to get involved in accidents due to their lack of driving experience and recklessness. Thus, a combination of driver fatigue and youth can be a deadly mix for potential vehicle crashes. Regardless, the findings of prior studies examining the link between driver age and fatigue are not conclusive. For example, although there were large differences among drivers in levels of alertness and performance, a driver fatigue and alertness study conducted by FMCSA (1997) showed no significant relationships between driver age and fatigue. On the other hand, Horne et al. (2002) indicated that younger drivers had a somewhat higher risk of being involved in fatigue-related accidents than older drivers. This finding is somewhat contrary to an observation made by Reissman (1997) that younger drivers often have greater flexibility adjusting to new sleep patterns than older drivers do. Also, Campagne et al. (2004) compared the performance of three age groups in a driving simulator study and found that deterioration of vigilance was correlated with driving errors for drivers aged 60 and above.

Another study conducted by Summala and Mikkola (1994) showed that record road accidents among 18-20 old drivers peaked during midnight to 6 a.m., whereas the accidents caused by drivers over 50 years old peaked during the late afternoon hours. More recently, Australian Transport Safety Bureau (2008) discovered that fatigued drivers under 29 years of age had a higher risk of vehicle crashes than those over 50 years old. It also showed a significant relationship between the age of the fatigued driver and the type of fatigue-related crash (single vehicle or head-on). Single vehicle crashes involved a higher proportion of fatigued drivers under 29 years of age compared with head-on crashes. However, fatigued drivers over 50 years of age were involved in more head-on crashes. This relationship might be linked to the time of crash. That is to say, single vehicle crashes are more likely to occur in the early morning and early morning crashes are more likely to involve fatigued drivers under 29 years of age. A similar logic could explain the relationship between older fatigued drivers and head-on crashes. Therefore, age can be a mediating factor for accidental risk. However, its importance to driver fatigue is unclear.

Obesity. Stoohs et al. (1994) found that obese truck drivers had a two-fold higher accident rate per mile than non-obese drivers. Similarly, a recent 15-month empirical study conducted by Park et al. (2009) subjected 456 commercial truck drivers to screenings for an obstructive sleep apnea (OSA) which disrupts sleep and results in daytime sleepiness, sleep attacks or "nodding off", impaired psychomotor ability, and poor decision-making ability. The study reported that approximately 2.4 – 3.9 million licensed commercial drivers in the U.S. might suffer from OSA due to their obesity, which would likely cause them to fall asleep at the wheel more frequently than physically-fitting drivers and thus increase accident risks.

Long driving hours. Long-haul drivers represent about half of the registered truck fleet in the U.S., but were involved in more than 90% of fatal truck crashes (FMCSA, 2003). This may be due to the fact that long haul (i.e., trips of 100 miles or more from the driver's home base) requires longer driving hours and thus increases the risk of vehicle crashes. Indeed, the relative risk of truck drivers who have driven more than eight hours was almost twice as high as those who drove lesser hours (Kaneko and Jovanis, 1990;

FIGURE 1
THE DRIVER FATIGUE INFLUENCE DIAGRAM

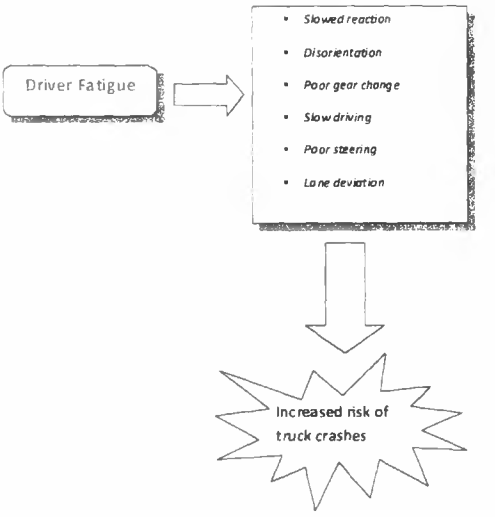
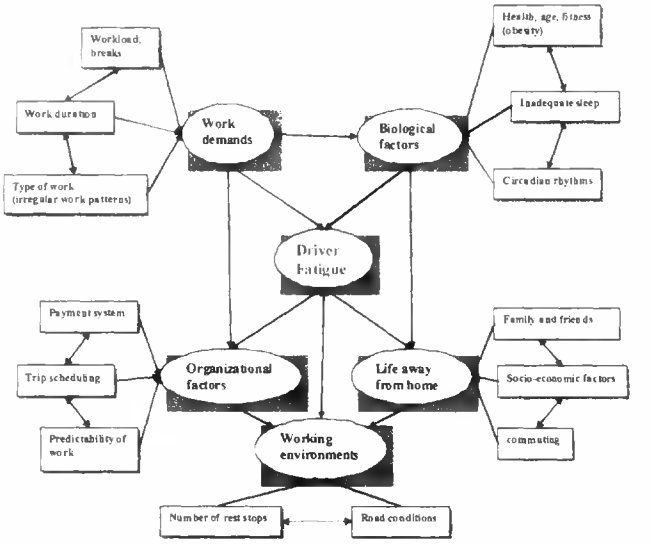


FIGURE 2
FACTORS INFLUENCING DRIVER FATIGUE



Source: Adapted and modified from Dawson, D., Feyer, A.M., Grander, P., Hartley, L., Haworth, N., and Williamson, A. (2001), *Fatigue Expert Group: Options for Regulatory Approach to Fatigue in Drivers of Heavy Vehicles in Australia and New Zealand*, Unpublished Discussion Paper, Melbourne, Australia: Australian Transportation Safety Board.

Braver et al., 1999; Heaton, 2005). Similarly, Mukherjee et al. (2006) discovered that a restriction on trips of no more than eight hours would reduce truck fatalities by 3-5% as compared to no such restriction.

Flexible driver schedules. Mackie and Miller (1978) observed that driving performance among truck drivers started declining after 5 hours of driving for drivers with irregular schedules as compared to 8 hours for drivers with regular schedules. As such, driver schedules can influence driver performance and the subsequent risk of truck crashes. Considering the impact of driver schedules on driver safety, a growing number of trucking firms have considered driver-friendly schedules, such as flexible schedules. For instance, flexible driver schedules resulting from the 24-hour restart provision often allow drivers to maintain a more routine (so-called rhythmic) driving schedule because they prevent the drivers from driving at odd hours and decrease off-duty time driving. As a result, a majority of drivers believed that such schedules would help them spend more time at home, increase their income, and thus improve their safety (Griffin et al., 1992).

Driver income. Truck drivers earn relatively low hourly wages as compared to most other comparable jobs (Belzer et al., 2002). To make matters worse, many drivers (especially non-union drivers) typically get paid only by the mile with no separate pay for non-driving work, such as their waiting and loading/unloading time at the dock. Under the current HOS rules, the opportunity cost of non-driving work can be too high for many drivers. This peculiar situation will force some drivers to violate the HOS rules and drive longer hours without sufficient breaks to make their ends meet and increase the risk of truck crashes. Indeed, the violations of HOS rules are on the steady rise. For example, 3.8% of the road-check inspection of motor carriers resulted in out-of-service conditions for HOS violations in 2005 that was slightly up from 3.44% in 2004 (Logistics Today, 2005). Braver et al. (1992) found that truck drivers who violated the HOS rules are more likely to fall asleep at the wheel and thus increase the risk of truck crashes. Thus, inadequate driver compensation may have a harmful effect on driver safety. Some studies such as Griffin et al. (1992) suggested that for every one cent increase in driver pay, there would be an 11.1% decrease in truck crash probability.

Monotonous driving. Due to a lack of stimuli, the monotony of road conditions can increase driver boredom and decrease driver performance. For example, driving performance degrades at a faster rate on straight road sections than on curves (Desmond and Mathews, 1998). In particular, sleep related accidents may be more common on long stretches of interstate highways and may account for 40% of fatal accidents (Shafer, 1993; McCartt et al., 1996). Likewise, driver fatigue is likely to occur much earlier when driving on straight, rural roads (Fell, 1994; Thiffault and Bergeron, 2003).

Vehicle speed. Since vehicle speed can either shorten or lengthen the truck driver's driving hours, potential traffic congestion and road construction along the driver's designated route can influence driver fatigue and the subsequent driver safety. Considering the potential link between vehicle speed and driver safety, both Malandraki and Daskin (1992) and Donati et al. (2006) developed a step function with consecutive time intervals that took into account changes in vehicle speed due to traffic congestions and unexpected delays on the road. Their studies revealed interdependence between vehicle speed and driver schedules/truck routes that, in turn, influence driver fatigue.

Preventive Measures for Driver Fatigue and Truck Crashes

As summarized in Table 2, driver fatigue can result in truck crashes and the subsequent fatalities, injuries, and property damages, and thereby burden motor carriers with a substantial amount of financial losses and decreased productivity. In the era of intensified competition in the trucking industry, motor carriers should develop viable guidelines to alleviate driver fatigue and then prevent the potential truck accidents/crashes, while complying with the HOS rules. With that in mind, we propose the following "best-practice" guidelines:

- Crum and Morrow (2002) found that starting the work week tired was the single most important factor influencing truck driver fatigue. To ensure adequate rest before the beginning of the work week, trucking firms should discourage long-haul drivers to follow disjoint sleep patterns and encourages them to have at least five hours of uninterrupted sleep by developing driver routes/schedules (especially post-trip) that allow frequent stops at home;

- To make the effective use of a driver's time to get adequate rest, trucking firms should minimize or eliminate the time a driver spends to count, load, and complete the paperwork, while minimizing the assistance of unnecessary lumpers who may prolong

the unloading time. Also, it is known that drivers tended to be more awake after lumping in the morning, but grew tired after lumping in the afternoon (Barnes, 2000). In other words, trucking firms need to find "driver-friendly" freight (e.g., automotive parts, grocery/food items, paper delivery) whenever possible;

- To minimize waiting/idle time at the unloading dock that takes away a driver's rest time and earning opportunities, trucking firms should consider using "drop-and-hook" options more frequently. In a typical drop-and-hook operation, the driver drops off a fully loaded trailer in the warehouse/distribution center yard and then hauls away an empty one without waiting for unloading. Thus, it saves the driver's waiting time. Also, this practice reduces fuel costs and carbon footprints since it eliminates the need for the truck to sit in the warehouse yard with its engine idling;

- To prolong the quality rest break, trucking firms should direct and encourage truck drivers to full-service rest stops where they can combine non-driving activities such as meal stops, stretches, refueling, shower, laundry, and social hours with the other drivers. Given the nationwide shortages of rest areas, the use of global positioning systems (GPS) along with satellite communication systems to locate nearest rest areas may be essential. Also, truck routes/delivery schedules should be restructured in such a way that drivers can have a greater access to these rest areas;

- According to Braver et al. (1992), the main reason why drivers violated the HOS rules are irregular route driving, penalty for late arrivals, carrying perishable goods, and being assigned unrealistic delivery deadlines. To minimize instances of HOS violations by truck drivers, trucking firms should negotiate with their shippers to allow the drivers to arrive at any time up to a certain time and day with open (soft) time windows as opposed to strict (fixed-schedule) delivery deadlines (Nixon, 2005). Also, the increased use of relay and team driving may help reduce the adverse impact of irregular route driving on the drivers;

- If the truck breaks down in the middle of the road, its driver would waste his/her valuable time for adequate rest and force the driver to catch up with his/her lost time by driving faster. Thus, thorough pre-trip inspection and preventive maintenance of the truck will help drivers make better use of their on-the-road off-duty time and subsequently reduce the potential risk of fatigue-related truck crashes.

The recent study conducted by NAVTEQ indicated that the use of a real-time navigation system which could alert drivers about unexpected traffic delays and ongoing road construction activities would help drivers save 18% of driving time on an average trip and increase fuel efficiency (Industry News, 2009). Considering this benefit, long-haul drivers may take advantage of this kind of device to better utilize their driving hours and thus increase non-driving restorative periods.

MYTHS ABOUT HOS IMPACTS USING SECONDARY DATA ANALYSIS

As discussed earlier, there were conflicting reports regarding the impact of HOS amendments on traffic safety in terms of reduced truck crashes. To further investigate the validity of this impact, we summarized the secondary data available from the U.S. Department of Transportation. As shown in Table 3, truck crashes declined a year after 2000, 2003 and 2005 HOS amendments despite steady increases in the number of vehicle miles, whereas those figures increased a year after 1996 HOS amendment. However, truck crashes seem to climb back gradually two year after each HOS amendment. As a matter of fact, the Wilcoxon signed rank test revealed that there was no statistically significant difference (p-value = 0.144) in truck crash statistics between four years before and after 2003 HOS amendment. Thus, it is difficult to make any concrete conclusions about the impact of HOS on traffic safety. To settle controversies surrounding the impact of HOS on the trucking industry, we looked at trucking business failures as a surrogate measure of the financial health of the trucking industry. As displayed in Figure 3, although there is a surge in trucking business failures in the third quarter of 2000 and the first quarter of 2001, past patterns of the trucking business failures tend to be cyclical and thus have little to do with any particular government mandates or rules. Instead, increases in trucking business failures seemed to be more correlated with economic downturns than any particular government policies or rules such as HOS amendments. For example, dramatic increases in trucking business failures in 2001 and 2007 coincided with recessionary economies during those years.

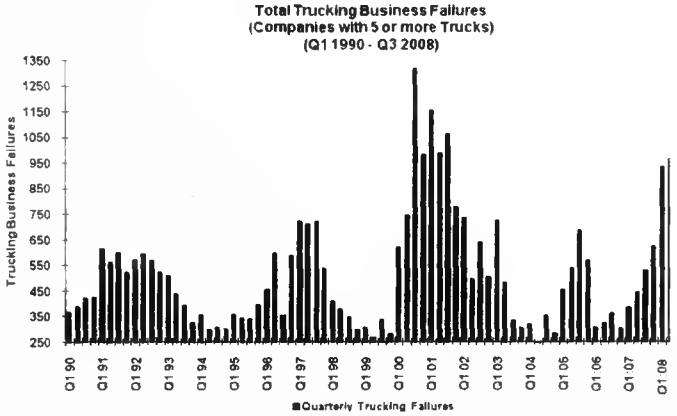
TABLE 3
CRASH RECORD FOR LARGE TRUCKS (GROSS VEHICLE WEIGHT RATING EXCEEDING 10,000 POUNDS) DURING THE PERIOD OF 1990 THROUGH 2007

Year	Recession year?	Trucks involved in crashes in total	Vehicle miles in millions
1990	Yes	384,776	146,242
1991	No	330,347	149,543
1992	No	376,035	153,384
1993	No	397,328	159,888
1994	No	460,644	170,216
1995	No	377,472	178,156
1996	No	393,755	182,971
1997	No	[redacted]	[redacted]
1998	No	411,955	196,380
1999	No	474,920	202,688
2000	No	456,955	205,520
2001	Yes	**429,823**	**209,032**
2002	No	434,587	214,603
2003	No	456,721	217,917
2004	No	**415,902**	**220,792**
2005	No	440,951	222,523
2006	No	**384,766**	**222,513**
2007	Yes	413,584	226,963
Aver		411,459 (39,461)	172,711 (84,076)

Note: Numbers in parentheses represent standard deviations.

Source: U.S. Department of Transportation, National Highway Traffic Safety Administration, National Center for Statistics and Analysis, *Traffic Safety Facts 2007, Final Edition* (Washington, DC), available at http://www-nrd.nhtsa.dot.gov/ as of March 2009.

FIGURE 3
TRUCKING BUSINESS FAILURES DURING THE PERIOD OF 1990 THROUGH 2008



Source: Avondale Partners, LLC, American Trucking Association (2008)

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

Since the inception of HOS regulations in 1939, these regulations have been controversial. Even the series of their amendments in 1962, 1996, 2000, 2003, and 2005 have failed to stop controversies and silence critics. The center of the controversies often lies in the misinterpretation and misunderstanding of their impact on reduction in driver fatigue and increase in driver safety/productivity. To compound the moot point surrounding HOS regulations, some study findings regarding the impact of HOS rules on driver safety are incongruent and inconsistent with each other. Thus, there is a great need for us to synthesize these study findings and discern real facts from misconceptions. With that in mind, this paper thoroughly reviewed various forms of prior studies including empirical, exploratory, case, and analytical studies that investigated the various effects of HOS rules on driver fatigue and safety, while analyzing secondary data sources available from the public domain. Based on the review of prior literature and secondary data sources, we can draw the following conclusions:

- The disruption of a truck driver's circadian rhythms resulting from irregular work or rest patterns is one of the most important reasons for driver fatigue. As driver fatigue increases, driver safety decreases due to a lack of reaction time, dexterity, memory, cognition, and feeling of alertness associated with driver fatigue. Thus, a series of HOS rules introduced in the past aimed to reduce driver fatigue by not only limiting the truck driver's duty hours, but also increasing off-duty rest periods. Despite this intention, HOS rules have become a constant source of controversies due to their oversight of long haul trucking practices. By nature, long haul trucking is characterized by extended and irregular duty hours that are often affected by many interwoven factors such as delivery schedules (including restricted time windows, nighttime driving), geographical customer bases, truck routes, driver shifts, driver earning opportunities, driver idle/waiting time at the loading/unloading docks, and number of different time zones that drivers need to pass. Thus, the effectiveness of HOS rules should be assessed holistically rather than being judged by their influence on each factor.

- For a variety of reasons including the carrier's delivery service commitments and the driver's concerns over his/her income, many drivers across the U.S. and Canada seemed to knowingly violate the HOS rules. Although electronic monitoring (through on-board recorders) of driver logs is available, its reliability is still questionable and the strict enforcement of the HOS rules on violators would significantly increase compliance costs for both carriers and federal agencies such as FMCSA. Thus, the FMCSA may need to ease the driver's burden of writing logs and reduce the dispatch manager's time to review and administer driver compliance regulations by reducing the frequency of writing logs and reviewing records.

- In addition to driver fatigue, truck driving environments such as the number of rest stops, dedicated parking areas, and road conditions (e.g., straight rural roads) are attributed to driver safety. Since the improvements of these environments require the state/federal governments' extensive time and monetary investments in transportation infrastructure, these environments are considered "given." Thus, dispatchers should be aware of these environments and restructure truck routes that can be adapted to these environments.

- It is inconclusive that HOS amendments drastically reduced traffic safety. Likewise, it is difficult for us to pinpoint the adverse economic impact of HOS amendments on the trucking industry from the macro-economic standpoint, although HOS compliances and enforcements will be costly.

As summarized above, various studies have been conducted to identify the sources of driver fatigues and their impact on trucking safety. However, there is still void left to fill in the literature to assess the effectiveness of HOS rules holistically. To point the right direction for future research endeavors, we suggest the following selected line of research topic areas that can help trucking firms improve transportation strategies in accordance with new HOS rules.

- Develop the best combination of duty and off-duty periods that add up to normal 24-hour circadian rhythms by simulating various combinations of duty and off-duty periods;

- Estimate the minimum recuperation time needed to compensate for interrupted sleep time by comparing various combinations of flexible driving schedules (e.g., shorter away from home versus longer at-home periods, Monday driving after home rests versus Friday driving after long driving on the road);

- Examine the effects of nighttime driving between midnight and 6:00 a.m. on driver safety with required off-duty periods that enable restorative sleep for drivers involving such nighttime driving versus without those required off-duty periods;

- Assess the impact of lumper hiring on the driver's productivity and fatigue;

- Determine the adequacy of sleep obtained in cab sleep-berth in comparison to sleep at the full service rest areas;

- Identify warning signals for potential truck accidents such as the driver's eye movement, eye-lid droop, and lane violations and then develop strategies/devices to monitor such signals;

- Develop profiles (e.g., age, gender, experience, physical fit) of truck drivers who are more prone to cause accidents as a result of fatigue by using data-mining techniques;

- Assess the economic impact of mandated electronic on-board recorders on long-haul operations and team/relay driving;

- Evaluate the impact of monetary incentives for drivers complying with the HOS rules on their productivity and safety records.

ACKNOWLEDGEMENTS

This research was partly funded by the Intermodal Transport Institute (ITI) at the University of Toledo and the U.S. Department of Transportation. The author also would like to express sincere gratitude to anonymous reviewers for their constructive critiques that helped improve the quality of this paper.

REFERENCES

Adams, B. (2005), "Confusing Times: New Hours-of-Service Rules Perplex Trucking Industry," *Business First*, Vol. 22, No. 13, pp. 61-62.

Arnedt, J.T., Wilde, G.J.S., Munt, P.W. and MacLean, A.W. (2001), "How do Prolonged Wakefulness and Alcohol Compare in the Decrements They Produce on a Simulated Driving Task," *Accident Analysis and Prevention*, Vol. 33, No. 3, pp. 47-54.

Amundsen, A.H. and Sagberg, F. (2003), *Hours of Service Regulations and the Risk of Fatigue- and Sleep-related Road Accidents: A Literature Review*, Oslo, Norway: Institute of Transport Economics.

Australian Transport Safety Bureau (2008), *Fatigue-related Crashes: An Analysis of Fatigue-related Crashes on Australian Roads using an Operational Definition of Fatigue*, Melbourne, Australia: Bureau of Infrastructure, Transport and Regional Economics.

Barnes, D. (2000), "Proposal to Reignite Battle over Fatigue Research," *Transport Topics*, May 8, p. 6.

Belzer, M.H., Fulton, G.A., Grimes, D.R., Saltzman, G.M., Sedo, S., and Schmidt, L.G. (2002), *Proposed Changes in Motor Carrier Hours of Service Regulations: An Assessment*, Unpublished Report, Ann Arbor, MI: Transportation Research Institute, University of Michigan.

Blanchard, D. (2004), "Now What? Hours of Service Rules Struck Down by Court of Appeals," *Logistics Today*, August, pp. 1-2.

Braver, E., Preusser, C., Preusser, D., Baum, H., Beilock, R., and Ulmer, R. (1992), "Long Hours and Fatigue: A Study of Tractor-Trailer Drivers." *Journal of Public Health Policy*, Vol. 13, No. 3, pp. 341–366.

Braver, E.R., Preusser, C.W., and Ulmer, R.G. (1999), "How Long-Haul Motor Carriers Determine Truck Driver Work Schedules and the Role of Shipper Demands," *Journal of Safety Research*, Vol. 30, No. 3, pp. 193-204.

Brown, I.D. (1993), "Driver Fatigue and Road Safety," *Alcohol, Drugs and Driving*, Vol. 9, No. ¾, pp. 239-252.

Business Wire (2008), "Truck-Involved Fatal Crash Statistics Fall to All-Time Low," February 8, www.allbusiness.com/government/government-bodies-office-us-federal-government/6641162-1.html, retrieved on October 19, 2009.

Clair, L.A. and Fox, S.D. (2004), "Time to Simplify Trucking Tariffs," *Supply Chain Management Review*, Vol. 8, No. 3, pp. 36-42.

Crum, M.R. and Morrow, P.C. (2002), "The Influence of Carrier Scheduling Practices on Truck Driver Fatigue," *Transportation Journal*, Vol. 42, No. 1, pp. 20-41.

Crum, M.R., Morrow, P.C., Olsgard, P., and Roke, P.J. (2001), "Truck Driving Environments and their Influence on Driver Fatigue and Crash Rates," *Transportation Research Record: Journal of the Transportation Research Board*, No. 1779, pp. 125-133.

Cutler, J. and Regan, M. (2007), "Hours of Service Development," *Logistics Quarterly*, Vol. 13, No. 5, p. 53.

Dawson, D., Feyer, A.M., Grander, P., Hartley, L., Haworth, N., and Williamson, A. (2001), *Fatigue Expert Group: Options for Regulatory Approach to Fatigue in Drivers of Heavy Vehicles in Australia and New Zealand*, Unpublished Discussion Paper, Melbourne, Australia: Australian Transportation Safety Board.

Desmond, P. A., and Matthews, G. (1996), "Task-Induced Fatigue Effects on Simulated Driving Performance," *Vision in Vehicles VI*, A. G. Gale, ed., Amsterdam, Netherlands: North-Holland.

Donati, A., Montemanni, R., Casagrande, N., Rizzoli, A., and Gambardella, L. (2006), "Time Dependent Vehicle Routing Problem with a Multi Ant Colony System," *European Journal of Operational Research*, Vol. 185, pp. 1174- 1191.

Eskandarian, A., Sayed, R., Delaigue, P., Blum, J., and Mortazavi, A. (2007), *Advanced Driver Fatigue Research*, Technical Report, Ashburn, VA: Center for Intelligent Systems Research, George Washington University.

Fairclough, S.H. and Graham, R. (1999), "Impairment of Driving Performance caused by Sleep Deprivation or Alcohol: A Comparative Study," *Human Factor*, Vol. 41, No. 1, pp. 118-128.

Federal Motor Carrier Safety Administration under U.S. Department of Transportation (1996), *Commercial Motor Vehicle/Driver Fatigue and Alertness Study*, http://www.fmcsa.dot.gov/facts-research/research-technology/publications/cmvfatiguestudy.htm.

Federal Motor Carrier Safety Administration under U.S. Department of Transportation (2003), http://www.fmcsa.dot.gov/about/news/news-releases/2003/052703.asp.

Federal Motor Carrier Safety Administration (2006), *Hours of Service of Drivers: Driver Rest and Sleep for Safe Operations: Proposed Rule*, Washington DC: U.S. Department of Transportation.

Fell, D. (1994), *Safety Update: Problem Definition and Countermeasure Summary: Fatigue*, Unpublished Report RUS No. 5, New South Wales, Australia: New South Wales Road Safety Bureau.

Fletcher, A. and Dawson, D. (2001), "Field-based Validations of a Work-related Fatigue Model based on Hours of Work," *Transportation Research*, Vol. F4, pp. 75-88.

Griffin, G., Rodriguez, J., and Lantz, B. (1992), *Evaluation of the Impact of Changes in the Hours of Service Regulations on Efficiency, Drivers, and Safety*, Publication No. 93, Fargo, ND: Upper Great Plains Transportation Institute, North Dakota State University.

Heaton, K. (2005), "Truck Driver Hours of Service Regulations: The Collision of Policy and Public Health," *Policy, Politics, & Nursing Practice*, Vol. 6, No. 4, pp. 277-284.

Heng, K., Hargarten, S., Layde, P., Craven, A. and Zhu, S. (2006), "Moderate Alcohol Intake and Motor Vehicle Crashes: The Conflict between Health Advantage and At-risk Use," *Alcohol and Alcoholism*, Vol. 41, No. 4, pp. 451–454.

Horne, J.A., Reyner, L.A., Baulk, S.D., and Flatley, D. (2002), "Driver Sleepiness: Overview of Recent Findings from Loughborough Sleep Research Centre," in Behavioral Research in Road Safety 2001, U.K. Department of Transportation.

Industry News (2009), "Real-Time Traffic Enabled Navigation System Can Save Drivers 4 Days a Year," http://www.egmcartech.com/2009/08/29/study-real-time-traffic-enabled-navigation-

systems-can-save-drivers-4-days-a-year/, retrieved on October 19, 2009.

Kaneko, T. and Jovanis, P.P. (1990), *Multiday Driving Patterns and Motor Carrier Accident Risk: A Disaggregate Analysis*, Davis, CA: Institute of Transportation Studies, University of California at Davis, Research Report UCD-ITS-RR-90-09.

Koukkari, W.L. and Sothern, R.B. (2006), *Introducing Biological Rhythms*, New York, NY: Springer.

Liskowsky, D.R. (2007), "Biological Rhythms and Shift Work," *Journal of the American Medical Association*, Vol. 268, No. 21, p. 3047.

Logistics Today (2005), "Hours of Service Violations are on the Rise," *Logistics Today*, Vol. 46, No. 6, p.1.

Mackie, R., and Miller, C. (1978), "Effects of Hours of Service, Regularity of Schedules and Cargo Loading on Truck and Bus Driving Fatigue," Coleta, C, Technical Report No. 1765-F.

Malandraki, C. and Daskin, M., (1992) "Time dependent vehicle routing problems: Formulations, Properties, and Heuristic Algorithms" *Transportation Science*, 26(33), 185-200.

Mitler, M.M., Miller, J.C., and Lipsitz, J.J. (1997), "The Sleep of Long-haul Truck Drivers," *New England Journal of Medicine*, Vol. 337, pp.755-761.

Mukherjee, A., Hall, R.W., and Shen, Z. (2006), *Bounds of Effectiveness, Costs, and Benefits of Driver Hours of Service Regulations for Freight Carriers*, Unpublished Report, Metrans Project 05-10, Los Angeles, CA: Epstein Department of Industrial and Systems Engineering, University of Southern California.

Office of Technology Assessment (1991), *Biological Rhythms: Implications for the Worker*, Washington DC: U.S. Department of Commerce.

Ogilvie, R.D. and Wilkinson, R.T. (1984), "The Detection of Sleep Onset: Behavioral and Physiological Convergence," *Psychophysiology*, Vol. 21, No. 5, pp.510-520.

Park, P.D., Durand, G., Tsismenakis, A., Vela-Bueno, A., and Kales, S. (2009), "Screening for Obstructive Sleep Apnea during Commercial Driver Medical Examinations," *Journal of Occupational and Environmental Medicine*, Vol. 51, No. 3, pp 275-282

Reissman, C.J. (1997), *The Alert Driver: A Trucker's Guide to Sleep, Fatigue, and Rest in our 24-Hour Society*, Alexandria, VA: American Trucking Associations, Inc.

Sagberg, F. (1999), "Road Accidents caused by Drivers Falling Asleep," *Accident Analysis and Prevention*, Vol. 31, No. 6, pp. 639-649.

Shafer, J.H. (1993), "The Decline of Fatigue Related Accidents on NYS Thruway," *Proceedings of the Highway Safety Forum on Fatigue, Sleep Disorders and Traffic Safety*, Albany, NY.

Stoohs, R.A., Guilleminault, C., Itoi, A., and Dement, W.C. (1994), "Traffic Accidents among Commercial Long-Haul Truck Drivers: The Influence of Sleep-Disordered Breathing and Obesity," *Sleep*, Vol. 17, No. 7, pp. 619-623.

Summala, H. and Mikkola, T. (1994), "Fatal Accidents among Car and Truck Drivers: Effects of Fatigue, Age, and Alcohol Consumption," *Human Factors*, Vol. 36, No. 2, pp. 315-326.

Thiffault, P. and Bergeron, J. (2003), "Fatigue and Individual Differences in Monotonous Simulated Driving," *Personality and Individual Differences*, Vol. 34, pp. 159-176.

U.S. National Transportation Safety Board (2008), http://www.truckinjuries.com/truck-driver-fatigue.html.

Van Cauter, E. and Turek, F.W. (1990), "Strategies for Resetting the Human Circadian Clock," *New England Journal of Medicine*, Vol. 322, No. 18, pp. 1306-1307.

WERC (2004), "Under the Gun: As the New Trucking Hours-of-Service Rules Takes Hold, Is the Warehousing Industry Ready?," *WERC Sheet*, March, pp. 1-3.

AUTHOR BIOGRAPHY

Hokey Min is James R. Good chair in Global Supply Chain Strategy in the Department of Management at Bowling Green State University. He was professor of supply chain management, distinguished university scholar and founding director of the UPS Center for World-wide Supply Chain Management and the Center for Supply Chain Workforce Development at the University of Louisville. Dr. Min earned his Ph.D. degree in management sciences and logistics from the Ohio State University. His research interests include global logistics strategy, e-synchronized supply chain, benchmarking, and supply chain modeling. He has published more than 100 articles in various refereed journals including *European Journal of Operational Research*, *Journal of Business Logistics*, *Journal of the Operational Research Society*, *Transportation Journal*, *Journal of Transportation Management*, and *Transportation Research*.