

CTBSSP

SYNTHESIS 20

Potential Safety Benefits of Motor Carrier Operational Efficiencies

A Synthesis of Safety Practice

TRANSPORTATION RESEARCH BOARD
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**Potential Safety Benefits
of Motor Carrier
Operational Efficiencies**

A Synthesis of Safety Practice

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COMMERCIAL TRUCK AND BUS SAFETY SYNTHESIS PROGRAM

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Administrators, commercial truck and bus carriers, government regulators, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and undervalued. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information available on nearly every subject of concern to commercial truck and bus safety. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the commercial truck and bus industry, the Commercial Truck and Bus Safety Synthesis Program (CTBSSP) was established by the FMCSA to undertake a series of studies to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern. Reports from this endeavor constitute the CTBSSP Synthesis series, which collects and assembles the various forms of information into single concise documents pertaining to specific commercial truck and bus safety problems or sets of closely related problems.

The CTBSSP, administered by the Transportation Research Board, began in early 2002 in support of the FMCSA's safety research programs. The program initiates three to four synthesis studies annually that address concerns in the area of commercial truck and bus safety. A synthesis report is a document that summarizes existing practice in a specific technical area based typically on a literature search and a survey of relevant organizations (e.g., state DOTs, enforcement agencies, commercial truck and bus companies, or other organizations appropriate for the specific topic). The primary users of the syntheses are practitioners who work on issues or problems using diverse approaches in their individual settings. The program is modeled after the successful synthesis programs currently operated as part of the National Cooperative Highway Research Program (NCHRP) and the Transit Cooperative Research Program (TCRP).

This synthesis series reports on various practices, making recommendations where appropriate. Each document is a compendium of the best knowledge available on measures found to be successful in resolving specific problems. To develop these syntheses in a comprehensive manner and to ensure inclusion of significant knowledge, available information assembled from numerous sources, including a large number of relevant organizations, is analyzed.

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FOREWORD

Administrators, commercial truck and bus carriers, government regulators, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and underevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

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PREFACE

*By Donna L. Vlasak
Senior Program Officer
Transportation
Research Board*

This synthesis focuses on motor vehicle safety practices and the impacts of these practices, measured from within the industry, and provides information that may assist motor carriers in deploying their vehicles in ways that minimize crash risk. A major theme is to make travel safer. Motor carrier executives and managers are the principal audience, although government and industry officials involved in highway operations, regulations, or outreach may find some results relevant.

The synthesis reports the research rationales and evidence for risk avoidance strategies and reports survey findings on their advisability, use, and perceived safety effects. It includes a literature review covering wide-ranging sources of research, crash and naturalistic driving data, and commercial products relevant to both efficiency and safety. It covered research literature and trade press, crash and naturalistic driving statistics, and vendor products and services.

Information was also obtained from motor carrier managers and other safety experts who were surveyed with regard to driver and vehicle deployment practices relevant to both effi-

ciency and safety. A convenience survey of interested, knowledgeable individuals, with 79 respondents out of 130, reports how current fleet safety managers view various driving situations and operational practices. Other safety experts in motor carrier safety included professionals in government, industry trade associations, and safety consulting and research and they were asked their opinions offering a different perspective on driver and vehicle deployment practices.

The report also includes 11 short case studies, reporting confidentially, and motor carriers' operational practices that might reduce exposure to risk. Several interviewees volunteered that they used commercially acquired software. Research and development gaps that have come to light are included here.

Ronald R. Knipling, Safety for the Long Haul, Arlington, Virginia, with principal contractor, Gene Bergoffen, MaineWay Services, Inc., Fryeburg, Maine, collected and synthesized the information and wrote the report. The Commercial Truck and Bus Safety Synthesis Program Oversight Committee members are acknowledged on page iv. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

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POTENTIAL SAFETY BENEFITS OF MOTOR CARRIER OPERATIONAL EFFICIENCIES

SUMMARY This report synthesizes current information on carrier operational efficiencies that may also provide safety benefits by decreasing exposure to risk. The report provides information that may assist motor carriers in deploying their trucks and buses in ways that minimize crash risk. This information was obtained through reviews of research; crash and naturalistic driving data; and commercial products relevant to both efficiency and safety. The project also obtained information from motor carrier safety managers and other experts who were surveyed with regard to driver and vehicle deployment practices relevant to both efficiency and safety. The report includes 11 short case studies of carriers' operational practices that might reduce exposure to risk. It also reports research and development gaps that have come to light in the study.

The report distinguishes between *risk reduction* and *risk avoidance* strategies in commercial motor vehicle transport. Risk *reduction*, constituting most of carrier safety efforts, improves the safety performance of individual “assets”—that is, drivers and vehicles. Risk reduction usually involves making company investments in proven interventions such as improved driver selection, training, management oversight, or vehicle safety equipment. Risk *avoidance* strategies are those in which carriers *deploy* their assets and otherwise conduct operations to minimize crash risk. In this conceptualization, risk avoidance takes the form of operational or route planning, or both, before trips or during a trip, before any immediate crash threat.

Risk avoidance strategies may also be conceptualized as carrier efficiencies with potential benefits to safety; hence the project title *Safety Effects of Carrier Efficiencies*. Most risk reduction strategies involve carrier resource allocations (costs) to achieve crash reductions (benefits). Here, the direct benefits are from operational efficiencies, but proven or potential indirect benefits also may come from crash reduction.

The project surveys of motor carrier safety managers and other experts on truck and bus safety were based on convenience samples of individuals active in national industry and research organizations. The primary project survey, a written questionnaire, was of motor carrier safety managers. The survey was designed to assess how respondents view various driving situations and operational practices with regard to safety. It also asked what specific practices they used, and their assessments of the safety effects of those practices. Another perspective was provided by a similar survey polling other experts in motor carrier safety. These individuals included professionals in government, industry trade associations, safety consulting, and research. These individuals are highly knowledgeable and experienced, but are not current practitioners at the carrier level. Thus, their survey was limited to questions on views and opinions, as opposed to practices.

Together, the project evidence and product review, surveys, and case studies indicate a number of common and beneficial risk avoidance strategies for carriers. In many cases, there is strong converging evidence of the safety benefits of particular strategies.

- Employing preventive maintenance;
- Reducing empty (“deadhead”) trips;
- Minimizing loading, unloading, and related delays;

- Optimizing routing and navigation
 - Providing navigational and routing aids
 - Assigning familiar routes to drivers;
- Selecting road type: divided versus undivided roads;
- Avoiding work zones;
- Avoiding traffic;
- Emphasizing efficient scheduling: optimal times for safe travel;
- Avoiding adverse weather;
- Using higher-productivity vehicles;
- Using onboard computers and mobile communications;
- Maximizing team driving;
- Using electronic onboard recorders;
- Optimizing fuel economy and safety:
 - Speed limiters
 - Monitoring driver fuel economy; and
- Monitoring vehicle condition.

In others, the evidence is suggestive but not unequivocal. Not every strategy is practical for all fleets. Most of the strategies addressed are inherently more applicable to truck operations than to buses. Many depend on economies of scale available in larger companies but not in smaller ones.

Project reviews of operational risk avoidance strategies have identified gaps in current knowledge and tools. Research could seek to gather and analyze data to more rigorously test and elaborate on current findings relating to carrier efficiencies and safety. Development efforts could be made to improve information analysis and to improve communications technologies to aid carrier operational planning and vehicle scheduling and routing. Industry recognition of the links between efficiency and safety, along with appreciation of the caveats, might enable more carriers to refine their operations in ways that also reduce their risks.

INTRODUCTION

BACKGROUND

There are two broad ways in which motor carriers can improve the safety of their operations. One is to improve the safety performance of their individual “assets”—that is, drivers and vehicles. Improving the safety performance of individual drivers and vehicles almost inevitably involves resource expenditures, such as spending more time and money on driver selection, training, management oversight, or vehicle safety equipment. These are proven ways to enhance safety.

Another method is to deploy the same assets in ways that minimize risk and increase opportunities for successful performance. This might be considered analogous to the decisions a football coach makes on game day. The potential performance capabilities of individual “assets” (players) are largely established before the game, but the coach’s lineup decisions and plays called during the game greatly affect team success. These methods do not primarily involve increased resource expenditures, but rather resource deployment decisions.

Various aspects of motor carrier safety management might be considered risk *avoidance* as opposed to direct risk *reduction* through safety performance enhancement (Dewar and Olson 2002; Murray et al. 2003; Knipling 2009). These include strategies such as the following:

- Emphasize scheduled, preventive maintenance on trucks, as opposed to reactive repairs;
- Minimize deadhead (empty trailer) trips;
- Minimize loading, unloading, and related delays;
- Optimize routing and navigation;
- Maximize travel on divided, limited-access roadways;
- Minimize travel on undivided roads;
- Avoid work zones;
- Avoid peak hours and congested roads;
- Avoid adverse weather and slick roads, when possible;
- Assign familiar routes to drivers;
- Encourage driving at off-peak times, when feasible;
- Optimize the mix of vehicle sizes (e.g., in some operations, use larger trucks to reduce the number of trips);
- Use onboard computers;
- Use mobile communications;
- Use driver teams;
- Use electronic onboard recorders (EOBRs);
- Improve fuel economy; and
- Monitor vehicle condition continuously.

Some strategies in this list are already in widespread use (Corsi and Barnard 2003; Knipling et al. 2003; Belella et al. 2009). Others are well established by research, yet not necessarily appreciated by industry. Still others have clear rationales, but are not firmly based on comparative data. Some risk avoidance strategies require proactive, executive-level strategic decisions by carriers. Others are dispatch and routing decisions made by operational managers, dispatchers, or drivers themselves. All involve operational efficiency measures with potential safety benefits when implemented intelligently.

This synthesis report reviews the rationales and evidence for these risk avoidance strategies, and reports survey findings on their advisability, use, and perceived safety effects. Motor carrier executives and managers are the principal target audience, though government and industry officials involved in highway operations, regulations, or outreach may find some results relevant. Many study topics are more relevant to trucking operations than to buses, primarily because trucking operations permit greater flexibility. Nevertheless, the study gathered data from both truck and bus sources, and provides findings relevant to both of these commercial vehicle types.

Overview of Crash Risk Avoidance

Operational risk can be seen within the context of crash risk in general. Crash *risk factors* may be distinguished from *proximal causes*. Risk factors exist before the crash event and affect the probability of a crash (Dewar and Olson 2002; Evans 2004; Shinar 2007; Knipling 2009). Much of road safety research seeks to identify crash risk factors and reduce risk. For example, the U.S.DOT Large Truck Crash Causation Study (LTCCS) was done to “identify associations between various factors and an increased risk of crash involvement in either relative or absolute terms” (Blower and Campbell 2005). Crash proximal causes, termed Critical Reasons (CRs) in the LTCCS, are the critical driver errors or other failures (vehicle, roadway) immediately preceding and triggering crash events. Figure 1, adapted from Knipling (2009), shows a simple time line of crash risk, cause, and occurrence. Both crash risk factors and causes may be human, vehicle, or environmental. Most proximal crash causes are human errors. In the LTCCS, CR assignments were 89% driver errors, 8% vehicle failures, and 3% roadway and environmental factors (Starnes 2006).

The risk time line in Figure 1 is extended to the left to show pre-trip and pre-crash threat periods. The operational practices

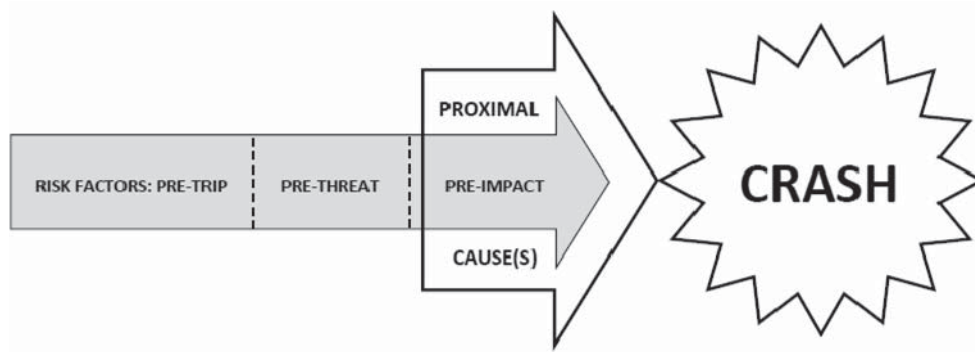


FIGURE 1 Risk-cause crash timeline with extended pre-crash risk segments. Adapted from Knippling (2009).

discussed in this report all fall into one or both of these periods. Pre-trip practices that affect risk include preventive maintenance, trip scheduling, pre-trip route optimization, and use of driver teams. Pre-crash threat practices include route selection to avoid undivided highways, traffic congestion, and work zones. The dotted lines between the risk zones denote that many risk avoidance practices operate across the zones. The next chapter will extend this conception into a two-dimensional framework for commercial motor vehicle (CMV) risk avoidance strategies based on the Haddon Matrix of road safety (Haddon 1980) and subsequent elaborations by CMV safety researchers (Faulks and Irwin 2002; Murray et al. 2003, 2009).

Efficiency and Safety Example: The Speed Paradox

Are trucks safer when traveling fast or slowly? The answer provides a prologue to several of the operational efficiencies discussed in this report. On one hand, driving too fast for existing conditions is the leading proximal cause of large-truck crashes. In the LTCCS, “too fast for traffic or road conditions” was the “Critical Reason” for 21% of truck at-fault crashes, versus 17% for inattention or distraction, 12% for inadequate surveillance (“looked but did not see”), 10% for all vehicle causes combined, and 7% for asleep-at-the-wheel (Starnes 2006).

On the other hand, when one considers the entire fleet of vehicles operating at any time and the normal ranges of truck

speeds (i.e., *not* traveling over the posted speed limits), fast travel appears to be dramatically safer than slow travel. This is demonstrated in naturalistic driving studies comparing exposure (based on a random sample of normal driving) to crash-relevant driving incidents (crashes, near-crashes, other traffic conflicts) captured in onboard recorders. Figure 2, based on data from an FMCSA-sponsored naturalistic driving study (Hickman et al. 2005), compares the vehicle speed profile of a random sample of driving (representing exposure) to vehicle speeds when incidents occurred. The first bar is the profile for exposure, the second the profile for incidents. For simplicity, just two travel conditions are shown: ≤50 mph and 51+ mph. Comparing the two bars, we see that slow travel is far riskier than fast travel, at least in regard to the kind of close traffic interactions captured in naturalistic driving. Trucks in the study were traveling at 50 mph or less only 16% of the time, but 63% of the incidents occurred at these slow speeds. The *risk odds ratio* is a statistical measure of the relative risk of two situations. In these data, slow travel was 8.9 times riskier than fast travel. The risk odds ratio was derived as follows: $(63\%/16\%)/(37\%/84\%) = 3.94/0.44 = 8.9$.

This counterintuitive finding may be termed the *speed paradox* (Knippling 2009). Though excessive speed is a major cause of serious crashes, most safety incidents occur when commercial vehicles are traveling relatively slowly. To understand this, consider the situations in which commercial vehicles must drive slower than regular highway speeds. Slow travel is associated with heavier traffic, undivided roads, closer

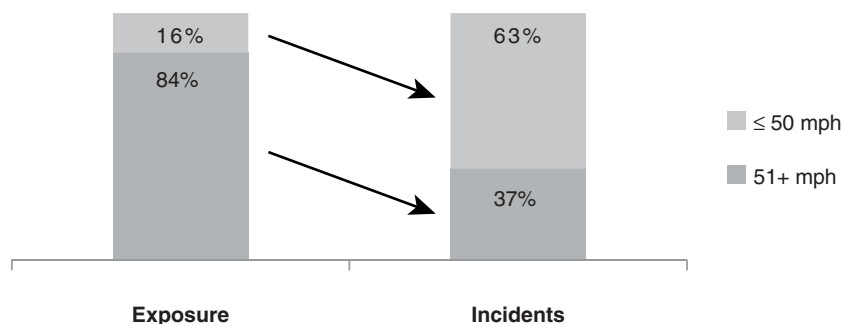


FIGURE 2 Relative risk by vehicle speed.

proximity to other vehicles, traffic signals, crossing traffic, and geometric constrictions such as narrow lanes, curves, and ramps. All of these road situations increase risk. Most of these especially elevate the risk of crashes with other vehicles, which constitute about 80% of large-truck fatal and injury crashes (FMCSA Analysis Division 2010). In contrast, fast travel usually means smooth and efficient flow. It follows that efforts to make commercial vehicle travel more efficient by avoiding potential delays are also likely to make that travel safer. This is a major theme of this report.

National Significance and Future Trends

This synthesis report focuses on carrier practices and the impacts of these practices measured from within carriers. Worth noting, however, is the aggregate national impact of carrier transport efficiencies. AASHTO (2010) recently published a report on freight mobility concerns in the present and, especially, for the future. The following excerpt from this *Unlocking Freight* report highlights the current and future national significance of CMV transport efficiency:

- By 2020, the U.S. trucking industry will move three billion more tons of freight than we haul today. To meet this demand, the industry will put another 1.8 million trucks on the road.
- In 20 years, for every two trucks now on the road, there will be an additional one . . . carrying the expected growth in food deliveries, goods, and manufacturing equipment.
- In 40 years, overall freight demand will double, from 15 billion tons today to 30 billion tons by 2050. Freight carried by trucks will increase 41 percent . . . The number of trucks on the road compared with today will also double.
- Between 1980 and 2006, traffic on the Interstate Highway System increased by 150%, whereas Interstate capacity increased by only 15%.
- On average, 10,500 trucks a day travel some segments of the Interstate Highway System. By 2035, this will increase to 22,700 trucks for these portions of the Interstate, with the most heavily used segments seeing upwards of 50,000 trucks a day.
- The amount of traffic experiencing congested conditions at peak hours in the nation's most urban areas on the Interstate System [has] doubled from 32 percent to over 67 percent.
- Major highway bottlenecks at urban Interstate interchanges cause tens of thousands of hours of delay each day, week, and year for truckers, business travelers, and commuters. Strings of bottlenecks are emerging along regional and transcontinental freight routes, creating corridors of congestion instead of corridors of commerce.
- Estimates of the truck hours of delay for the worst freight-truck bottlenecks show that each of the top 10

highway interchange bottlenecks cause over a million truck-hours of delay per year, costing \$19 billion overall.

- Delays and idling trucks at bottlenecks and chokepoints exacerbate negative air quality impacts on the surrounding communities.

Unlocking Freight did not address safety concerns related to freight congestion. The speed paradox described previously, along with other evidence to be presented in this report, testify to the adverse safety impacts of traffic congestion and other sources of travel inefficiency.

PROJECT OBJECTIVES, METHODS, AND SCOPE

This report on *Safety Effects of Carrier Efficiencies* synthesizes current information on carrier operational efficiencies, which may also provide safety benefits by decreasing exposure to risk. It provides information that may assist motor carriers in deploying their trucks and buses in ways that minimize crash risk. The project has involved the following information-gathering activities:

- Research evidence and product review:
 - Research literature and trade press;
 - Crash and naturalistic driving statistics; and
 - Vendor products and services.
- Surveys:
 - Carrier safety-manager questionnaire; and
 - Other-expert (e.g., research, government, trade association) questionnaire.
- Carrier safety-manager interviews (for case studies).

The survey and interview methodologies are described in chapters focusing on those efforts. The research literature and vendor product review methodology is described here. Searches were done using websites, academic databases, books, trade press publications, and articles. The following databases were used to conduct the reviews:

- Transportation Research Information Database (TRID): Offers the largest online bibliographic database of transportation research, with more than 650,000 records of published research.
- Business Source Premier: Features the full texts of more than 2,200 journals. Full texts from as early as 1965 are provided, and searchable cited references, from as early as 1998.
- Lexis Nexis: Provides access to a multitude of popular articles as well as some scholarly works. There is also access to congressional records, court decisions, and government statistical reports.
- EconLit: From the American Economic Association's electronic database, covers economic literature, with more than 735,000 records.

These databases were searched using a variety of topic-related keywords and phrases, often in combinations to

improve focus. Keywords included: trucking, safety, crash risk avoidance, motor transport efficiency, truck routing software, preventive maintenance, traffic, road risk, safety strategies, construction, work zones, reversing safety, and efficiency benefits.

The remaining chapters of this report present this information and draw conclusions regarding carrier efficiencies with

safety benefits or other effects. Chapter two presents evidence and product information relating to strategies potentially affecting efficiency and safety. Chapter three describes the methods and results of the project surveys. Chapter four presents several carrier case studies. Chapter five summarizes findings regarding current and emerging carrier practices, as well as needs and opportunities for further research. An appendix to the report provides the project survey forms.

EVIDENCE AND PRODUCT REVIEW

This chapter presents research findings and, where applicable, product information relating to motor carrier risk avoidance strategies. Most of these are carrier efficiencies that also have benefits, or at least potential benefits, for safety. The chapter begins with a conceptual framework for Commercial Vehicle Operations (CVO) risk avoidance strategies based on the Haddon Matrix (discussed here) and on subsequent considerations of how that concept could be better fitted to motor carrier safety. The chapter then addresses the following carrier practices and issues:

- Employing preventive maintenance;
- Reducing empty (“deadhead”) trips;
- Minimizing loading, unloading, and related delays;
- Optimizing routing and navigation
 - Providing navigational and routing aids
 - Assigning familiar routes to drivers;
- Selecting road type: divided versus undivided roads;
- Avoiding work zones;
- Avoiding traffic;
- Emphasizing efficient scheduling: optimal times for safe travel;
- Avoiding adverse weather;
- Using higher-productivity vehicles;
- Using onboard computers and mobile communications;
- Employing team driving;
- Using EOBRs;
- Optimizing fuel economy and safety
 - Speed limiters
 - Monitoring driver fuel economy; and
- Monitoring vehicle condition.

The last four topics in this list were not among the topics originally planned for the study, but were added based on survey responses and interview inputs. The chapter ends with a discussion of whether there is a general relationship between efficiency and safety, in industry and in CMV transport in particular.

Three disclaimers are in order regarding the following discussion:

- No product or service was formally evaluated for this report. Company and brand names provided are illustrative of available products and services. Neither TRB nor this report endorses any company, product, or service.
- There are regulatory issues and activities under way regarding several of the earlier noted practices and

equipment. This report addresses only their operational use by carriers, not regulatory questions.

- Project survey data are based on convenience samples of responding safety managers and other experts. Survey data represent the opinions and practices of the respondent samples, not of larger populations such as “all carrier safety managers.” Safety-manager respondents generally represented larger fleets with sufficient resources and safety interest to participate in national industry organizations and meetings.

CONCEPTUAL FRAMEWORK FOR COMMERCIAL VEHICLE OPERATIONS RISK AVOIDANCE STRATEGIES

This section provides a conceptual framework for carrier operational risk avoidance strategies based on past literature. The Haddon Matrix (Haddon 1980) is a framework for understanding and designing crash reduction strategies. It provides a conceptual structure for identifying factors that influence crash occurrence by dividing the crash scenario in terms of time frame (i.e., pre-crash, crash, and post-crash) and in terms of the primary “actors” affecting the event (Howarth et al. 2007). The “actors,” or categories of factors affecting crashes, are the human (primarily driver), the vehicle, and the roadway and environment. Thus, the conventional Haddon Matrix is a 3×3 matrix consisting of three rows (pre-crash, crash, and post-crash) and three columns (human, vehicle, and roadway and environment). Table 1 presents the conventional Haddon Matrix with examples in each cell.

The Haddon Matrix was a seminal, heuristic contribution to motor vehicle safety and is a foundation for worldwide programs to reduce crashes (Williams 1999; Runge 2003). However, Will Murray (Murray et al. 2003, 2009) and others (e.g., Faulks and Irwin 2002) have pointed out that the conventional Haddon Matrix is insufficiently detailed for conceptualizing the full array of interventions applicable to CMV transport. Murray et al. (2003) added a column, “Management Culture,” and listed 33 carrier, industry, and government practices that affect safety, with most in the pre-crash time frame. Murray et al. (2009) reconceptualized and further expanded the columns to include six factors:

- Management culture;
- Journey;
- Road and site environment;

enduring (e.g., driver personality, vehicle design, and roadway design) and those that are temporary (e.g., driver rest status, vehicle condition, and weather). Accordingly, each of these three categories can be split into enduring versus temporary, for finer classification of safety interventions. Additional columns are added for macro-level (government, industry, and society) and motor carrier factors, though most often these actors affect safety through specific effects on drivers, vehicles, or roadways. Table 2 includes these expanded breakouts and classifies the safety strategies of this report into an expanded CVO Safety Matrix based on the project review of the research and product literature, project surveys, and carrier interviews. All of the strategies addressed in this report are pre-trip and pre-threat interventions affecting one or more of the following factors:

- Driver temporary states;
- Vehicle design and equipment;
- Vehicle condition;
- Roadway design and traffic patterns; and
- Road environment condition (e.g., weather).

In most cases, the safety benefits of the practices listed in Table 2 are well established. For at least two interventions (vehicle size changes and onboard computers and communications), net safety benefits or disbenefits are not exclusively determined. They are still listed as strategies for consideration. One intervention, optimizing times of travel, relates strongly to two crash risk factors: driver temporary states (e.g., night driving during low circadian periods) and roadway design and traffic patterns (i.e., varying traffic density at different times). These factors may operate in opposite directions at different travel times, thus complicating the problem of optimizing times of travel.

PREVENTIVE MAINTENANCE

Mechanical deficiencies are common in large trucks, reflective of their large size, many components, and operational use. In the LTCCS, 40% of crash-involved trucks had some vehicle-related deficiency or malfunction, although these were the proximal cause (Critical Reason or CR) for only about 4% of crashes (excluding cargo shifts, which were another 2%). In the LTCCS, vehicle deficiencies as associated factors were more common for combination-unit trucks (CTs) (43% of involvements) than for single-unit trucks (STs) (33%). There was a clear association with crash category and fault (CR assignment), as follows:

- Truck single-vehicle crash involvements: 62%;
- Truck multivehicle involvements, truck at-fault: 50%; and
- Truck multivehicle involvements, truck not-at-fault: 21%.

These high percentages for vehicle condition as an associated factor were seen in the LTCCS because every crash-

involved truck was given a full safety inspection. Other crash data files based on standard police investigations usually generate lower percentages because these investigations only note obvious system failures (Blower 2009). Roadside inspection statistics for FY2010 indicate that 19.5% of trucks and 6.5% of buses were placed out-of-service (OOS) owing to vehicle faults (FMCSA 2010). Note, however, that roadside inspections are targeted toward higher-risk carriers and thus do not represent a random sample of commercial vehicles in transport.

In spite of these statistics, better carriers, including those accessible to this study through project surveys, generally have well-established and effective vehicle maintenance programs. In well-managed fleets, as much as 80% of vehicle maintenance is planned rather than reactive (Arsenault 2010). Corsi and Barnard (2003) conducted a survey of “best safety performers” to identify and define their safety management programs and policies, including some practices covered in this report. They identified 148 safe motor carriers through a two-step process that included review of SafeStat performance data and obtaining recommendations from FMCSA State Division Directors. An extensive survey was completed by these 148 safe carriers and formed the basis for their report. The study found that 56% of these fleets used computerized equipment maintenance programs, with the percentage ranging from 78% for the largest fleets to 23% for the smallest. Most (61%) of their computerized programs generated specific part failure analyses. Such percentages would likely be higher today, given the advancement of technologies and data systems supporting vehicle maintenance.

Supportive attitudes toward fleet vehicle maintenance were strong in the Corsi and Barnard (2003) study. About 76% of carriers agreed or strongly agreed with the statement, “Cost is no issue when it comes to keeping our vehicles defect-free.” About 80% agreed that, “Deploying a defect-free fleet is the most important thing we can do to ensure highway safety.” In *CTBSSP Synthesis 1, Effective Commercial Truck and Bus Safety Management Techniques* (Knipling et al. 2003), the project safety survey asked managers to rate the effectiveness of 28 fleet safety management practices. Regularly scheduled vehicle inspection and maintenance was rated the most effective of the 28 practices. In the present project survey, 77 of 79 safety-manager respondents reported using a preventive maintenance (PM) schedule and record for each vehicle, and 62 of 78 used PM software or spreadsheets. Both practices were rated among the most effective of the carrier practices presented. Ironically, perhaps, vehicle condition was rated as among the factors with the least effect on overall crash risk among the five factors presented (enduring driver traits, temporary driver states, vehicle factors, roadway characteristics and traffic, and weather). This finding might partially reflect that, as with the two earlier surveys cited, the current survey drew its respondents primarily from among safety-conscious fleets. These results may characterize these better fleets, but should not be considered representative of the entire industry.

Greater involvement of drivers and other employees in vehicle management appears to have safety benefits for companies. Wright et al. (2005) analyzed safety programs in 12 Australian trucking companies. Firms that encouraged involvement of their workers in vehicle maintenance lowered maintenance costs, reduced crashes, and experienced less time spent by drivers away from work because of injuries. Four of the companies experienced reduced insurance costs and improved vehicle utilization through reduced OOS time.

The project survey did not ask respondents to state whether the PM spreadsheets and other software they used were self-developed or commercially acquired. In the 11 case study interviews, several interviewees volunteered that they used commercially acquired maintenance management software.

A review of these products' websites reveals numerous ways that truck maintenance software can assist fleets. These include helping fleets and other truck maintainers to better manage PM schedules and tasks, parts inventory, fuel and tire use, and other maintenance-related needs. These systems are marketed on the basis of reducing costs, improving productivity, increasing warranty recoveries, improving auditing and billing, and generally making vehicle and other equipment maintenance more systematic. In most systems, information entered once is used in the system to support a number of different user needs by populating various maintenance reports and schedules. For example, vehicle number is entered for every action on a vehicle, so that a complete vehicle maintenance history is always available. These records assist maintenance technicians in daily tasks and also support higher-level, fleet-wide analysis and planning. Specific data applications include:

- Scheduling PM;
- Generating work orders;
- Setting work standards for tasks;
- Tracking maintenance costs by vehicle, mile, hour, or other denominators;
- Recording equipment usage and inventory;
- Comparing equipment and maintenance procedure costs and reliability;
- Documenting licensing and inspections;
- Identifying and analyzing trends;
- Managing recalls;
- Purchasing parts and services;
- Bar-coding parts for further efficiencies;
- Managing warranties;
- Managing depreciation;
- Managing fuel use; and
- Tracking tools and other maintenance equipment.

The product websites also include fleet maintenance improvement case studies and testimonials from maintenance managers. Among the current case studies, Carrier I provided the fullest explanation of their use of truck maintenance software. Carrier I has its own truck maintenance facility and man-

ages PM using TMT Fleet Maintenance software. The software is used to manage PM schedules, parts inventory, fuel and tire usage, and other maintenance schedules and records. Data on equipment assets and maintenance activities are entered once, and then integrated by the software into various user-formatted reports as an aid to equipment management and budgeting.

In a *Transport Topics* editorial, Arsenault (2010) notes that vehicle maintenance is one of seven "BASICS" in the new FMCSA Comprehensive Safety Analysis 2010 (CSA 2010) program. CSA enforcement practices increase the importance of vehicle maintenance and the value of automating PM planning for carriers:

As any fleet maintenance manager will attest, it is extremely difficult to manually maintain a schedule of regular preventive maintenance services and inspections, track maintenance histories, cross-reference driver complaints with repair orders and produce documentation on demand. The regulations don't mandate the use of maintenance management software, but it certainly may make CSA 2010 compliance less arduous. . . . [The] software application simplifies this process and makes it much easier to comply with CSA 2010.

Question 30 of the safety-manager survey asked respondents to identify the operational efficiency or other practice contributing *most* to fleet safety. The following are responses relating to the general topics of vehicle maintenance and inspections:

- Conducting a thorough pre- and post-trip inspection;
- Proper pre- and post-trip inspections, driver debriefing and communication;
- Insistence on daily management monitoring of pre- and post-trip inspections;
- Driver and maintenance staff input; and
- Preventive maintenance and pre- and post-trip inspections.

REDUCING EMPTY ("DEADHEAD") TRIPS

One of the simplest ways to improve safety through improved efficiency is to reduce the number of unproductive, non-revenue trips and miles. Reducing empty miles is primarily motivated by financial gains, but there is a proportional benefit to safety. The textbox provides a simple hypothetical model to illustrate how safety is enhanced by reducing empty backhauls.

Reducing empty trips is one of the operational practices being examined in the Motor Carrier Efficiency Study (MCES). The MCES (Delcan Corporation 2007a,b; Belella et al. 2009) is a congressionally mandated program to identify inefficiencies in freight transportation, evaluate safety and productivity improvements made possible through wireless technologies, and demonstrate wireless technologies in field tests. Phase I of the study has gathered extensive data on carrier inefficiencies in seven categories: equipment and asset utilization, fuel economy and waste, loss and theft, safety (i.e., crashes),

Empty Backhauls and Safety: A Hypothetical Model

A simple, “back-of-the-envelope” math model illustrates the safety gains, relative to productivity, from reducing dead-head trips. Suppose, hypothetically, that a trucking fleet’s miles are 80% full and 20% empty. Assume that all its miles (full and empty) carry the same crash risk. During Year 1, the company has 120 police-reported crashes carrying 8 million ton-miles of freight. In relation to productivity, that equals a rate of 15 crashes per million ton-miles. During Year 2, it uses the same trucks and same drivers, and logs the same number of total miles. It makes no safety improvements in its individual trucks and drivers, and has the same crash rate per mile. Thus, it again has 120 crashes. But it uses load brokers, load boards, and other means to reduce its empty miles by half. Thereby, the company runs 90% full and 10% empty, and carries 9 million ton-miles of freight. During Year 2, its crash rate in relation to productivity is 120 crashes per 9 million ton-miles or 13.3 crashes per ton-mile. That is an 11% improvement from Year 1. These hypothetical calculations are described for one fleet, but in principle extrapolate to the entire national fleet. They illustrate the safety effects of reducing deadheads and, more generally, how carrier efficiencies can result in risk avoidance apart from traditional risk-reduction efforts.

maintenance, data and information processing, and business (including driver) management. Phase II will involve pilot tests of specific efficiency improvements. Reducing empty miles falls under the MCES category of equipment and asset utilization. The project literature review report (Delcan Corporation 2007a) states the following rationale:

Motor carrier equipment is effectively utilized when it is in the process of generating revenue, by the mile, the hour, or by any other mutual agreement between the motor carrier and their customer. Ideally, equipment would operate around the clock with neatly planned and minimal down time for routine maintenance, repairs, or refueling; equipment on-the-clock for the purposes of serving the customer would always be compensated, there would be no deadhead, unauthorized, or out-of-route miles, and trucks would never have to wait for or travel empty to pick up the next load. However, asset utilization is not optimized in real world operations. Additionally, disconnects between certain types of motor carrier operations and shipper/receiver/customer operations exist as continuing impediments to optimal asset utilization.

The MCES (Delcan Corporation 2007a) quotes several estimates placing empty miles at about 20% of total miles for for-hire carriers. The percentage appears to be decreasing slowly as companies do a better job of obtaining backhauls. The report cites a National Private Truck Council (NPTC) estimate that the percentage is about 25% for private fleets. Drayage operations have higher percentages, with empty trucks adding considerably to traffic congestion in the vicinity of major U.S. ports. The report estimates total U.S. large-truck empty miles at 40 billion annually. It estimates the potential financial gain to carriers from eliminating empty miles to be \$2.7 billion.

In 2008, the U.S. large-truck fatal crash rate was 1.64 per 100M vehicle-miles traveled (VMT), and the fatality rate was 1.86 per 100M VMT (FMCSA Analysis Division 2010). This suggests that approximately 656 fatal crashes and 744 fatalities that year involved empty trucks. The total truck crash rate was 160.4 per 100M VMT. Applying this rate to 40 billion empty miles suggests approximately 64,000 associated crashes. These estimates, like the textbox model presented previously, assume that crash rates are unchanged when trucks are empty.

For-hire carrier sales and dispatching focus in large part on reducing empty miles. Delivery contracts are often written to establish routes that minimize empty miles. Private fleets may function as for-hire fleets by seeking backhaul loads. Carriers obtain backhaul loads through load brokers, load boards, and development of long-term service contracts with shippers. Economies of scale favor larger carriers in aggressively reducing empty miles, with some large firms attaining empty ratios of 10% (Delcan Corporation 2007a). Reducing empty backhaul rates is also popular with drivers because, in most operations, they are not paid for empty miles.

Web-based load boards (also called freight boards) and load brokers are an efficient and economical means for matching loads to trucks. Service providers offer round-the-clock online service, route searches, shipment tracking, routing aids, credit reports, and both carrier and shipper quality ratings based on user feedback. Uship, for example, provides a profile and customer feedback-based ratings for each carrier (by shippers) and for each shipper (by carriers). Individual comments on carriers from shippers, and on shippers from carriers, are listed. For each carrier, there is an overall feedback score, positive feedback percentage, and customer ratings on four scales (communications, care of goods, punctuality, and service as described).

In the project surveys, reducing empty backhauls was regarded by safety managers as having modest benefits for fleet safety. Respondents were asked to rate the safety benefits of reducing empty miles on a seven-point Likert scale ranging from -3 (“*Reduces Fleet Safety*”) to +3 (“*Improves Fleet Safety*”). The overall safety-manager mean rating was +0.5. A later question asked whether the carrier, “Use[d] brokers of other services to reduce empty backhauls (dead-heads).” Among truckload carrier respondents, 21 of 27 indicated that they did. Among users of such services, the practice received a 3.1 mean Likert scale rating on a 1-to-5 scale of safety effectiveness.

Most for-hire carriers represented in the project case studies made strong efforts to minimize their empty miles. One large company, Carrier B, has taken advantage of its size and used multiple means to a 10% deadhead rate, which the interviewee considered to be a major accomplishment. Carrier E, a medium-sized truckload carrier, has a 12% deadhead rate, which has allowed it to pay its drivers for empty miles. This

eliminates one source of driver discontent and improves driver retention. Improved driver retention, though outside the scope of this report, is itself an operational efficiency that is highly supportive of safety (Staplin et al. 2002; Knippling 2009).

MINIMIZING LOADING, UNLOADING, AND RELATED DELAYS

In almost any work activity, waiting is an unproductive use of time and reduces efficiency. Excessive delays associated with truck loading and unloading, also known as *driver detention*, affect safety as well. Drivers generally are unable to use wait times for sleep or other restorative rest. Thus, wait times use up drivers' available waking hours, thereby contributing to later fatigue when they are finally driving. Further, drivers may be thrown off-schedule by excessive waits, thus causing frustration and a later urge to drive faster or otherwise increase work speed unwisely. Under current hours-of-service (HOS) rules, drivers' tours-of-duty are limited to 14 hours. This has the benefit of preventing longer work periods, but raises the potential for drivers to rush to reach a destination within 14 hours.

A new report by the U.S. Government Accountability Office (GAO 2011) addresses the issue of commercial driver detention times. GAO's summary findings included:

- Detention of drivers at shipper or receiver facilities is a prevalent problem; of 302 drivers interviewed by GAO, 204 (68%) reported being detained within the past month.
- Of those drivers who had experienced detention, 80% stated that it affected their ability to meet HOS requirements, and 65% reported losing revenue as a result of being detained.
- Shippers and receivers control many of the factors leading to driver detention, such as facility staffing, loading and unloading equipment, quality and promptness of service, and the readiness of products for pickup.
- Shippers often disagree with carriers and drivers about the length of detention time and its causes.
- Carriers have some ability to mitigate the problem by charging detention fees to shippers, developing better working relationships with customers, improving communications, and abandoning shipper accounts where detention is a problem.
- The "hook and drop" method, whereby a truck arrives with an empty trailer and leaves with an already-loaded trailer greatly reduces the problem, but requires more equipment, coordination, and space.
- Larger carriers have greater resources and more leverage with clients than smaller carriers, and thus are generally able to mitigate the problem more effectively.
- The quantitative contribution of driver detention to HOS violations and to crashes is not known.

Under the sponsorship of the FMCSA, the Trucking Research Institute conducted an experimental study of the

effects on driving alertness of truck loading and unloading tasks (O'Neil et al. 1999). There was no consistent evidence of driving fatigue resulting from the physical activity. Instead, drivers complained about the time required and unplanned delays associated with loading and unloading. Moreover, because drivers in many segments of CMV transport do not load and unload their vehicles, the question of excessive physical work is often moot. Instead, the problem revolves around detention times.

CTBSSP Synthesis 1: Effective Commercial Truck and Bus Safety Management Techniques (Knippling et al. 2003) asked safety-manager and other-expert respondents to rate the relative importance of 20 CMV transport safety problems. The problem was stated as, "Delays associated with loading and unloading (e.g., resulting in long working hours, tight schedules, and fatigue)." In Likert scale ratings, the item was judged the fifth most important safety problem by safety managers and the fourth most important by other experts. About half of the respondents considered it one of the top five problems among the 20 presented.

The MCES Inefficiencies Report (Delcan Corporation 2007b) identified operational inefficiencies recognized as most pressing by motor carriers, cited evidence of their effects, and evaluated potential technological solutions. These inefficiencies were defined as practices, procedures, incidents, or events that produce waste, generate unnecessary expenses, require excess effort, do not generate revenue, or do not contribute to safe, secure, and timely cargo transport. The MCES study team conducted stakeholder workshops in seven U.S. locations in which representatives from motor carriers, technology vendors, and other industry experts discussed transport inefficiencies. Excessive waiting for loading and unloading was the most frequently cited "high-priority" inefficiency across the stakeholder groups. This was the top inefficiency concern of truckload (TL), less-than truckload (LTL), and intermodal carriers (Belella et al. 2009). Carriers expressed particular frustration regarding excessive waits for their trucks to be unloaded at consignee locations as well as at intermodal terminals. Border crossing wait times were also cited.

Loading and unloading inefficiency is costly for carriers and their drivers, who routinely bear the expense of waiting. Delcan Corporation (2007b) estimated the average truck waiting, loading, and unloading time at pickup and delivery points to be 2 hours, with much of the time spent waiting. According to the report, there is a potential annual financial gain of \$3.1 billion for U.S. carriers and \$6.6 billion for society as a whole from the elimination of this transport inefficiency. The most affected CMV transport operations are motor carriers of containers (e.g., port drayage operators), regional and long-haul TL carriers, and grocery and agricultural LTL carriers. For deliveries, the problem often affects private carriers as much as it does for-hire carriers, because most of their deliveries are to customers whose trucks are treated the same as for-hire trucks. The problem is less significant for private car-

riers loading at their own facilities and for those delivering to their own stores or other facilities (Delcan Corporation 2007b).

According to carriers reporting to the MCES and those interviewed for the current study, shippers and receivers may be relatively indifferent to the costs incurred by carriers and drivers while waiting. Further, shippers' and receivers' own efficiency may actually benefit from practices that create steady truck queues while their own operations proceed on schedule without workload spikes or interruptions. Gate reservation and appointment systems could alleviate the problem, although carriers reporting to the MCES argued that their use was geared toward optimizing facility efficiency rather than reducing truck waiting times.

One corporate vice president for safety interviewed for the study believed that carrier use of EOBRs had an indirect benefit of reducing loading and unloading delays. That is because EOBRs reinforce the notion that HOS compliance is nonnegotiable, and also because they provide more compelling documentation of delivery schedule disruptions caused by excessive dock delays.

The MCES (Delcan Corporation 2007b) suggested a wireless communications application concept called *Virtual Queuing* as a logistical and technological intervention to reduce excessive loading and unloading delays. Virtual queuing would extend queues to trucks reaching the vicinity of the terminal. It would allow consignees to monitor and dynamically reschedule dock operations to compensate for delays in both truck arrivals and departures from the facility.

On project surveys, respondents were asked to rate the safety benefits of "reducing loading and unloading delays" on a seven-point Likert scale ranging from -3 ("*Reduces Fleet Safety*") to +3 ("*Improves Fleet Safety*"). Among safety managers, the overall mean rating was +1.8. Among other-expert respondents, the mean rating was +1.4. For both groups, these were among the highest mean ratings for driving situations and practices presented.

Several of the case study carriers assign dedicated routes to successful, experienced drivers. These assignments are coveted. In addition to keeping drivers on familiar roads, dedicated runs provide a stable income, predictable home times, and more regular work-rest cycles.

For carriers, the most obvious and feasible means to reduce excessive delays is to charge a fee to shippers and receivers for excessive wait times. These *detention fees* are written into shipping contracts, with 2 hours appearing to be the most common threshold for fees. Affected drivers may receive all or most of the money charged. Safety-manager respondents were asked whether they charged detention fees to customers for excessive loading and unloading delays. The question was omitted from bus operator forms. Among all responding carriers, 34 of 50 charged detention fees. Among TL carrier

respondents, the proportion was 23 of 27. The safety effectiveness of the practice was given a mean rating by users of 3.4 on a 1-to-5 Likert scale. Several interviewees for case studies used detention fees. One interviewee considered them effective, but added that "aggressive" enforcement and collection was essential for reducing excessive delays and their negative safety consequences. Another lamented that the practice was not highly effective because the fees became a corporate-to-corporate billing issue, rather than a penalty felt directly by frontline depot supervisors with the most influence on the problem.

The following are two safety-manager survey comments relating to loading and unloading delays:

- Inefficiencies of shippers/receivers in the loading and unloading process has the most negative effect on safety for our drivers.
- Our biggest challenge is with our customers and suppliers. There is an ignorance or apathy towards an efficient loading or unloading process.

OPTIMIZING ROUTING AND NAVIGATION

Smoother routing and navigation improve the efficiency of CMV operations. The following quotation from the MCES literature review report (Delcan Corporation 2007a) summarizes the importance of optimized routing for operational efficiency: "Each time a truck accrues additional miles due to less than optimal routing, the equipment is not being utilized to its full potential, and it does not complete its intended mission in the least possible time, with the least possible costs in labor, equipment wear, and fuel." Improved routing efficiency appears to aid safety as well. There are two primary safety rationales for aiding routing and navigation. The first is avoiding exposure, especially to higher-risk roads, that is, roads likely to be congested with traffic or otherwise hazardous. The second is easing drivers' navigation workloads. Making navigation easier for drivers reduces distraction and associated crash risk. This section explores these benefits and describes products aiding CMV routing and navigation.

A distinction can be made between *routing* and *navigation* in CMV operations (Bennett 2009). *Routing optimization* generally refers to improvements in the efficiency of an overall pickup-and-delivery sequence, as in a full driver tour-of-duty or multiday trip. Routing optimization can also be applied to a whole fleet or company. *Navigation aids* more often refer to devices to assist drivers in making a particular point-A-to-point-B trip.

Providing Routing and Navigational Aids to Drivers

Portable and vehicle-installed Global Position System (GPS) devices are marketed as aids to navigation and mobility, not

as safety devices. Yet the proper use of automated GPS navigation aids by commercial drivers supports safety by the two mechanisms mentioned earlier: reduction of risk exposure and easing driver mental workload. With regard to risk exposure, reductions can simply be in the quantity of exposure (i.e., reducing mileage for the same productivity) and in exposure to higher-risk road conditions.

Truck-specific navigation aids can steer drivers clear of roads where truck traffic or hazardous cargo is restricted or prohibited. They can warn drivers of low-clearance underpasses (e.g., bridges with less than 14 ft of vertical clearance, the national standard for local roads and collectors), low-weight-bearing bridges, or other hazardous locations. Systems can route drivers around higher-risk roads, such as undivided roads and those with high traffic densities. If systems are updated, they can route drivers around work zones or road closures. The relative risks associated with some of these road types and conditions will be documented in the following sections. Systems can also route trucks to avoid toll roads, although this diversion practice is more likely to be detrimental to safety, as toll roads generally have safer design features than do non-toll alternate routes (Short 2006).

Any system that routes trucks away from higher-risk roads and toward lower-risk roads reduces overall crash risk independently of driver and vehicle risk factors. Truck-specific road information is needed, however. Leone (2010) reports the experience of trucking company Transport America, two of whose trucks were involved in bridge underride crashes in the preceding year. In one case, the driver was following a paper map, and in the other, the driver was following a general-purpose navigation device. Neither driver was aware that the route included low-clearance underpasses. The safety manager interviewed for Case Study D (Large Truckload Carrier) told of similar mishaps related to truck drivers using general-purpose navigation aids. A bill proposed (though not under immediate consideration) in New York state would outlaw commercial drivers from using general-purpose GPS units (Leone 2010).

Multiple vendors provide truck-specific routing and navigation aids. Major communications providers can offer integrated, truck-specific navigation systems with their systems. Specific features and services of truck-specific routing and navigation aids may include:

- U.S.- and Canada-wide street-level map data with turn-by-turn directions;
- Routing in accordance with height restrictions, low-weight bridges, seasonal road closures, and so forth;
- Best “practical” versus shortest routing choices;
- Optimized stop sequences;
- Truck-specific toll costs;
- Fuel optimization for cost and in accordance with company purchase plans;
- Hazardous materials and larger-truck-size routing;

- Intermodal rail versus truck routing and cost comparisons;
- Customized routing by specification of preferences or routes to be avoided;
- Manual override of specified routing;
- “Location radius” tool to search for points of interest within specified distances of any location;
- Geofencing (restriction of vehicles within or outside of specified zones);
- Driver rest stop options in compliance with HOS rules;
- Identification of weigh stations along routes;
- Identification of intermodal rail ramps;
- Automation of fuel and mileage tax tracking;
- Integration with communications systems for real-time management;
- Web access to routing and navigation functionality;
- Data downloads to spreadsheets or other programs; and
- (Being developed) Dynamic adjustments based on real-time assessments of traffic and weather conditions.

Potential GPS benefits touted by vendors include better real-time dispatching, increased productivity, improved HOS compliance, decreased overtime, lower fuel use, improved customer service, validation-of-service calls, lower insurance costs, and decreased driver speeding. One deficiency of most truck-specific navigation systems is that they route to an address, not to a delivery entrance. For large delivery locations, this means that drivers may still be at a loss to pinpoint their exact destination. Manual “last-mile” directions are still needed (Leone 2010). Another, more significant concern is that different vendors may gather their own highway data themselves or through independent contacts with state and local agencies. There is little standardization across different vendors and products.

In an article on route optimization benefits, Bennett (2009) quotes Ken Snow, president of Hagopian Cleaning Services, on the company’s successful use of route optimization software. The company’s fleet consists of 27 vans used for carpet and upholstery cleaning. Snow estimates that route optimization reduces company mileage by 5% to 10%, or 25,000 to 50,000 annual miles. This is reduced exposure to crash risk. Route optimization also provided fuel savings and the elimination of the manual task of route planning for the trucks. Each evening, the company runs the route optimization program to plan the next day’s routes. Onboard GPS units would aid drivers in A-to-B trips, but would not optimize the sequences of multiple stops of a truck or multiple trucks of a fleet. Larger companies with multiple fleet locations can network the application to optimize regional coverage. A vendor interviewed for the article claimed that companies with as few as four vehicles could benefit from route optimization software. For mobile maintenance or other service operations, trips back to a central depot can be reviewed to determine whether they could have been avoided by better provisioning of the vehicle before its departure. Another company representative interviewed for the article reported the results of a company survey of drivers

using a routing and navigation aid system. The survey found that 85% of company drivers believed the system helped them every day to travel more efficiently and with less stress.

On project surveys, respondents were asked to rate the safety benefits of using routing and navigation aids on a seven-point Likert scale ranging from -3 (“Reduces Fleet Safety”) to +3 (“Improves Fleet Safety”). The item was stated as, “Increase routing efficiency using GPS navigation aids and/or truck routing software.” Among safety managers, only one respondent out of 77 assigned the practice a negative rating, and the overall mean rating was +1.8. Among other experts, there were no negative ratings among 31 respondents and the mean rating was +1.1.

With regard to carrier practices, 42 of 76 respondents said their drivers use general-purpose GPS systems, and 29 of 77 used truck-specific systems. There was considerable overlap among the users of the two types, suggesting that in many fleets some drivers use general systems, whereas others use truck-specific systems.

Assigning Familiar Routes to Drivers

Driving involves three types or levels of performance and skill: controlling the vehicle, responding to driving events (e.g., other traffic, signs, and signals), and navigation. Excessive attention to any one of these levels can interfere with performance on the others. For example, novice drivers are typically preoccupied with controlling the vehicle, to the detriment of their ability to respond to traffic events (Shinar 2007). Similarly, excessive attention to navigation can reduce attention to basic vehicle control and, in particular, traffic events. Think about your own driving on roads that you drive every day, compared with your driving on unfamiliar roads. For experienced drivers on familiar roads, both vehicle control and navigation are automatic. One can anticipate and attend closely to traffic conditions and specific threats. On unfamiliar roads, drivers are not as able to anticipate specific roadway and traffic risks. This is particularly true when drivers are looking for a specific turn or destination.

Situation awareness is the ability to “effectively filter information in a data-rich environment,” or simply “knowing what is going on” (Shinar 2007). The primary task of driving includes controlling the vehicle and responding to traffic events. Any secondary task such as navigation can reduce performance on the primary task.

LTCCS statistics showed a relation between truck drivers’ roadway familiarity and crash involvement. The LTCCS had no mileage exposure database or non-crash control data set, so relative rates of crash involvement cannot be discerned. One can, however, use LTCCS data to discern associations between roadway familiarity and fault in crashes, with the assumption that a higher incidence of fault also implies higher risk. Figure 3 shows three categories of LTCCS truck crash involvements and, for each, the percent of truck drivers who were unfamiliar with the road. That is, they had never or only rarely driven the road before. Overall, 26% of LTCCS drivers were unfamiliar with the roads on which they crashed. When crash involvements were disaggregated by driver unfamiliarity with the roadway, one sees a strong relationship with crash fault and type of crash involvement.

On project surveys, respondents were asked to rate the safety benefits of assigning familiar routes to drivers when possible. As with similar questions, respondents were presented with a seven-point Likert scale ranging from -3 (“Reduces Fleet Safety”) to +3 (“Improves Fleet Safety”). The overall mean for safety manager-respondents was +1.7. Among other experts, the mean rating was +1.6.

Beyond roadway familiarity, are there other strategies managers and dispatchers could use in assigning routes to drivers? One prudent strategy is to assign more difficult and risky routes to more experienced and competent drivers. Or, stated another way, avoid the situation in which an inexperienced or otherwise questionable driver is exposed to higher-risk traffic or roadway conditions. Knipling (2009) presented a hypothetical mathematical model suggesting that this strategy would reduce overall fleet crash risk because it would reduce the dangerous convergence of the weakest drivers with the most hazardous roadway situations. The model assumed a

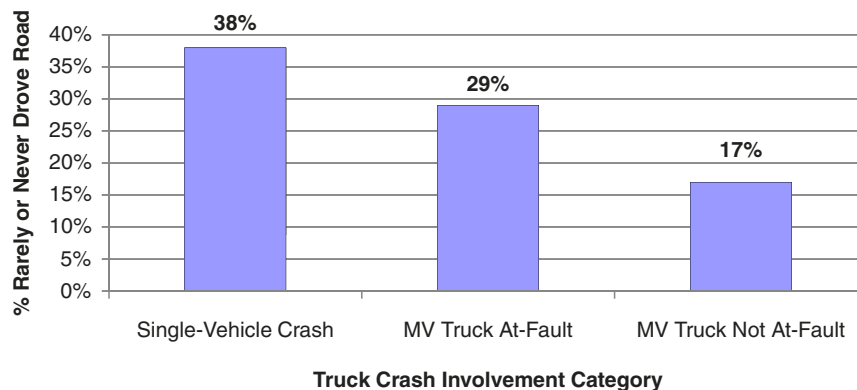


FIGURE 3 Road unfamiliarity and crash involvement.

multiplicative relation between relative driver risk and relative road risk.

ROAD SELECTION: DIVIDED VERSUS UNDIVIDED ROADS

Recall the speed paradox presented and discussed in chapter one. Statistics were presented showing that, perhaps contrary to intuition and expectations, truck travel at speeds above 50 mph was generally far safer than travel under 50 mph. A principal reason underlying the speed paradox is that most higher-speed truck travel is on divided highways, whereas most lower-speed travel is on undivided roads. Further, most divided highways have limited access (i.e., entrance- and exit-ramps), whereas undivided highways are open-access.

The safety advantages of divided over undivided highways are well known to road designers and others in road safety. About 85% of large-truck crashes involve another vehicle, and interaction among vehicles is greatest on undivided roadways. On undivided roads there are traffic signs and signals, crossing traffic, stops and starts, turns, pedestrians and bicyclists, and generally greater opportunities for distractions and other driver mistakes. On divided highways, vehicles are all traveling at about the same speed with minimal interaction and few crossing-path events. Thus, divided highways have much lower crash rates. Overall, Interstate highway fatal crash rates are about one-half those of non-Interstate arterial roads, and just one-third those of local roads (FHWA 2000). In eight studies cited in the FHWA website on crash modification factors (www.cmfclearinghouse.org), the road design countermeasure “install roadway median” reduced crash rates by an average of 49%.

Harwood (2006) emphasized the limited-access feature of most divided highways in the following comments regarding roadway design and CMV safety:

The lowest crash rates on our roadway systems are on limited-access highways, for example, freeways and toll roads. Higher crash rates occur on multilane non-freeways where direct access is permitted, including both multilane divided highways and multilane undivided highways. Two-lane highways have the highest crash rates. Across the mix of highway types, crash rates differ by at least a factor of 3 or 4 between typical rural two-lane highways and rural freeways.

Naturalistic driving data provide a compelling testimony to the risks of driving on undivided versus divided roads. Traffic conflicts (including crashes, near-crashes, and other incidents) captured by onboard sensors and videos are classified by their conditions of occurrence and other characteristics. In this case, the condition of interest is roadway separation (divided versus undivided). In addition, researchers randomly select a large sample of exposure observations, or “exposure points,” representing normal driving. These “exposure points” are also classified by conditions of occurrence. Researchers then compare the frequencies of conditions (e.g., divided versus undivided

TABLE 3
UNDIVIDED VERSUS DIVIDED HIGHWAYS: COMPARISON
OF NATURALISTIC DRIVING EXPOSURE POINTS TO
TRAFFIC CONFLICT DATA

Roadway Type	Event Type	
	Exposure (%) (N = 1,072)	Traffic Conflict (%) (N = 907)
Undivided	113 (10)	248 (38)
Divided	959 (90)	559 (62)
Total	1,072 (100)	997 (100)

highways) in the traffic conflict sample with those of the exposure points. Any condition overrepresented in the traffic conflict sample can be considered a safety risk factor.

These comparisons demonstrate the disproportionate risk associated with driving on undivided highways. Table 3 compares 1,072 baseline epochs (representing exposure) to 907 traffic conflicts (crashes, near-crashes, and other incidents) from a long-haul truck naturalistic driving study (Hickman et al. 2005; Knippling et al. 2005). The percentage breakdowns are shown. Most divided roads in the study were Interstates or other freeways.

Only 10% of the driving was on undivided highways, but 38% of the traffic conflicts occurred on those roads. The majority of traffic conflicts occurred on divided highways (62%), but the risk relative to exposure was much greater on undivided roads. The odds ratio between undivided and divided roads for traffic conflicts was calculated to be 5.3 $[(248/113) / (559/959) \approx 5.3]$. Figure 4 shows the same relationship graphically.

In the LTCCS, 38% of CT crashes occurred on undivided (including one-way) roads, a percentage identical to that in the naturalistic driving study. Percentages were similar for single-vehicle and multivehicle CT crashes. A larger percentage of LTCCS ST crashes (55%) was on undivided roads. STs have somewhat higher crash rates per mile traveled than do CTs, reflective of their greater exposure on undivided roads. In 2008, 54% of large-truck fatal crashes and 52% of nonfatal crashes occurred on undivided highways (FMCSA Analysis Division 2010). No national exposure estimates using the same definitions are available for comparison to crashes, but there is no question that the exposure percentage is much smaller.

These statistics indicate that carriers could reduce risks by making concerted efforts to dispatch and route trucks on divided highways. For load pickups and deliveries, it may not be possible to reduce exposure significantly to undivided highways. Greater opportunities exist in trip planning between loading and delivery points. The statistics suggest that, when given a choice, trucks are safer on divided highways even if that means significantly greater mileage.

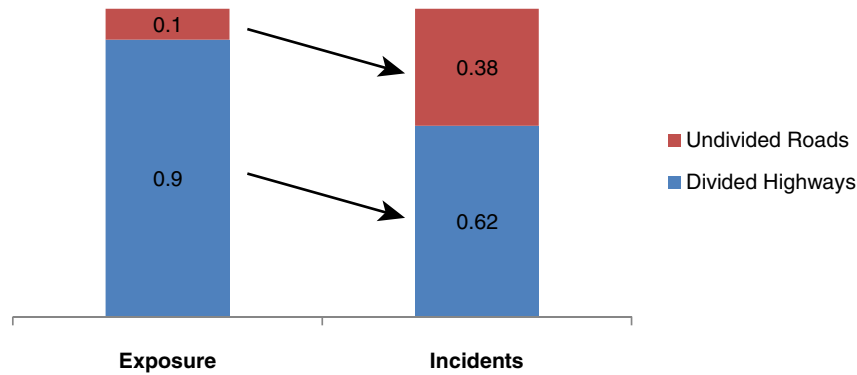


FIGURE 4 Undivided and divided roads.

An extension of the earlier findings and logic applies to the toll road avoidance strategy known as “diversion.” Diversion (Short 2006) occurs when trucks or other vehicles eschew toll roads to avoid paying the tolls. Often this is on a parallel undivided highway. There are about 2,800 mi of toll roads within the 42,800-mi Interstate highway system, and about 1,800 additional mi of non-Interstate toll roads (Short 2006). Many toll roads operate at below-capacity volumes, in part as a result of diversion. No one knows how many trucks and other vehicles divert from these roads to avoid tolls, or the effects of diversion on overall crash rates. It is important that carriers and drivers carefully weigh their road choices by factoring relative crash risks into their decisions.

In the safety-manager surveys, “maximizing travel on Interstates and other freeways” was among four factors tied for the highest mean rating (+1.8 on a -3.0-to-+3.0 scale) of the 11 driving situations and practices presented. Its opposite, maximizing travel on low-speed roads, received the lowest mean rating (-1.1). For other experts, the corresponding values were +1.7 (the second highest rating for 15 practices presented) and -1.6 (the highest negative rating). With regard to toll reimbursements to drivers, 66 of 78 responding carrier representatives indicated that they provided “EZ Pass transponders and/or reimbursement of toll charges to drivers/OOs [owner-operators].” The practice received an average rating of 3.8 on the five-point safety effectiveness scale.

On the other-expert survey, a respondent provided the following comment (with no sources cited for statistical statements):

The biggest single determinant of overall safety is risk exposure. Interstates, because they are divided trafficways with no at-grade intersections, are 400% safer than U.S. and State routes. More than 70% of fatal truck crashes occur on these latter roads, not Interstates where all the enforcement attention and focus takes place. Carriers operating mostly on non-Interstate roads are much more at-risk than those that predominantly travel up and down Interstates.

Almost all of the case study carriers equip their vehicles with toll transponders and actively encourage travel on divided

roads. Several use routing software maximizing travel on these roads. Others pre-plan trips in detail, including road choices.

AVOIDING WORK ZONES



In 2008 there were about 10,000 large-truck crashes in work zones, about 3% of all truck crashes. These included 166 fatal crashes, 4.4% of the total of 3,733 for the year (FMCSA Analysis Division 2010). About one-fourth of all work zone fatal crashes involved a large truck. Roadway- and traffic-related crash threats in work zones include constricted lanes, narrow or absent shoulders, makeshift signs, and traffic back-ups where light vehicles may dart in front of trucks to move up in the queue. An FHWA website (www.workzonesafety.org) contains crash data, research reports, driver training materials, and other information on work zone safety, including information on major highway work projects.

In the same naturalistic driving data as discussed earlier (Hickman et al. 2005), trucks drove in highway work zones in only 8 of 1,072 randomly selected exposure-point observations (0.7%). During the same driving, they had 55 of 914 traffic conflicts in highway work zones (6.0%). Although these data are based on relatively few work-zone observations, they suggest greatly elevated risk. The calculated odds ratio for conflict involvement in this data set is 8.5 $[(55/8)/(859/1,064) \approx 8.5]$.

The elevated crash risk in work zones is not specific to trucks. Khattak et al. (1999) found that changes in crash rates during the construction were about the same for cars and trucks. Truck crash severity was not increased by roadwork, but work zone crashes tended to involve more vehicles than those on normal roads.

Murray et al. (2005) analyzed work zone crashes and suggested truck-related improvements. The study found rear-end and sideswipe crashes to be among the most common scenarios. Work zone fatal crashes are more likely than non-work zone crashes to involve multiple vehicles. Nearly one-third of fatal work zone crashes involve a truck, although the study did not determine relative fault or principal causes. Work zone crash countermeasures suggested by the study included crossroad rumble strips, driver feedback signing (warning of excessive speed), highway advisory radio, and detection and warning of traffic queues.

Thirteen percent of truck-crash involvements in the LTCCS occurred in work zones. Almost all of these involvements were in multivehicle crashes. Trucks were assigned the CR (were at-fault) in 42% of these. Of *all* truck at-fault LTCCS crashes, 11% occurred in work zones. Many of these were rear-end crashes in which trucks struck cars, suggesting liability for trucks and their carriers.

In the safety-manager survey, avoiding construction zones received an average rating of +1.4 on the -3-to-+3 Likert scale. For other experts, the mean rating was +1.3. In both cases, it was in the top half of safety practices but not among the very top. In safety-manager interviews, work zones were cited several times as being among the risky road conditions to be avoided for safer operations. Two carriers described specific efforts to avoid them. One carrier codes work zones on its internal crash reports and has identified them as high-risk areas. Another carrier provides drivers with daily state traffic alerts that include information on major work zones.

AVOIDING TRAFFIC

The speed paradox (chapter one) and other evidence presented previously suggest that disrupted traffic flow elevates crash risk. Heavy traffic has become a dominant feature of urban travel. The Texas Transportation Institute (TTI; <http://mobility.tamu.edu>) publishes annual reports on urban traffic congestion and its effects on mobility (Schrank and Lomax 2009). In 2007, Americans lost 4.2 billion hours to urban congestion. This was a small reduction of about 1% from the previous year, but was still more than five times the urban delay 25 years ago. Across the United States, delay has increased in all types of urban areas, whether relatively small, medium-sized, or large. In larger urban areas, free traffic flow occurs reliably only between the hours of 9:00 p.m. and 5:00 a.m. In 1982, peak morning congestion lasted about 75 min, from about 7:30 a.m. to 8:45 a.m. Equivalent congestion now lasts almost 3 hours from about 6:30 a.m. to 9:15 a.m. For evening peak hours, 1982's 90-min peak, between about 4:00 p.m. and 5:30 p.m., is now seen for twice as long, between about 3:30 p.m. and 6:30 p.m. The Travel Time Index is the ratio of travel time in the peak period to travel time at free-flow conditions. Since 1982, the index has risen steadily from 1.09 to 1.25. That means that urban travel times during peak hours are 25% slower than during free-flowing conditions.

TABLE 4
TRAFFIC DENSITY: COMPARISON OF NATURALISTIC
DRIVING EXPOSURE DATA TO RISK DATA

Traffic Density	Event Type	
	Exposure (%) (N = 1,072)	Traffic Conflict (%) (N = 914)
Heavy (C,D,E,F)	36 (3)	145 (17)
Medium (B)	258 (24)	216 (24)
Light (A)	778 (73)	543 (59)
Total	1,072 (100)	914 (100)

Increases in traffic density and travel times generate disproportionate increases in the number of proximal interactions among vehicles and associated crash risk. This is perhaps best seen in naturalistic driving data. Large-truck naturalistic driving methodologies and statistical findings relating to traffic density and risk are similar to those presented earlier for undivided highways and for work zones. Table 4 shows exposure and traffic conflict percentages for different levels of traffic density from Hickman et al. (2005). As with earlier examples, these are based on researcher observation and classification of video views of surrounding traffic. A six-level classification scheme has been used to classify exposure points and conflicts. Light (A) means free-flowing traffic, medium (B) means flowing with some restrictions (owing to the presence of other vehicles), and heavy (C–F) means various degrees of restricted traffic flow. Table 4 shows these three groupings with heavy listed first as it is the highest-risk condition.

In the table, notice the disproportionately high risk for heavy traffic density, equivalent risk for medium density, and lower risk for light traffic. The odds ratio of conflicts to exposure for heavy traffic (levels C, D, E, and F) compared with lighter levels (A and B combined) is 5.9, indicating that incident risk is about six times greater in heavy traffic. Also notice, however, that the majority of conflicts still occurred in light traffic, even though relative risk was lowest.

About half of all LTCCS truck-crash involvements occurred on urban roads, although only 28% were cited as having a “traffic factor.” LTCCS trucks were at-fault in 45% of their multivehicle crashes in urban areas, versus only 33% in rural areas (Knipling and Bocanegra 2008). Trucks were also more likely to be at-fault in crashes where traffic was a factor, perhaps related to blind zones around trucks.

In the project survey, both safety managers and other experts were asked to rate the driving practice “Avoid urban rush hours and other heavy traffic situations.” As with other practices, they rated the safety value of the practice on a seven-point Likert scale, from -3 to +3. The practice received a mean rating of +1.7 from safety managers, making it one of the highest-rated practices. The other-expert mean rating of +1.2 was near the middle of the 11 practices rated.

Most of the case study interviewees regarded traffic density as a major factor in crash risk. Carrier G uses truck routing software which in its algorithms considers traffic characteristics in the vicinities of delivery locations. Carrier J, located in upstate New York, monitors New York and surrounding state traffic alerts daily to warn drivers of congestion.

In a research partnership with the American Transportation Research Institute (ATRI), the FHWA Office of Freight Management and Operations has developed the Freight Performance Measures (FPM) program. FPM (www.freightperformance.org) provides extensive freight travel speed data for the U.S. highway system. Initial analyses have been of speeds and travel time reliability on five major U.S. freight corridors: Interstates I-5, I-10, I-45, I-65, and I-70. Travel speed data have been collected from more than 500,000 operational trucks equipped with GPS-based automatic vehicle location equipment. Trucks are assigned an anonymous identification number to maintain the confidentiality of truckers and trucking companies. The system receives position (latitude and longitude) and time and date data from trucks at regular intervals to provide data for the travel speed analysis. Trucks that stop (e.g., for refueling, deliveries, or rest) are excluded from the calculations.

An FPM service (“FPMweb”) allows carriers and other users to obtain information on travel speeds and delays for any given place and time along 25 Interstate highways: I-5, I-10, I-15, I-20, I-24, I-25, I-26, I-35, I-40, I-45, I-55, I-65, I-70, I-75, I-76, I-77, I-80, I-81, I-84, I-85, I-87, I-90, I-91, I-94, and I-95. Users may generate Geographic Information System (GIS) maps, detailed analyses of individual corridors, or broader analyses across corridors.

One ATRI study (Short et al. 2009) used FPM data to identify the 30 worst freight bottleneck locations in the United States. This was based on FPM calculations of hourly and total “Freight Congestion Value” for these locations. “Freight Congestion Value” was defined as the freight vehicle population times the average vehicle miles per hour below free flow (i.e., 55 mph). This was calculated hourly and in total. The study did not include crash counts, but the evidence cited in this report suggests the same locations would be high-crash-risk as well. A more recent analysis lists 100 such sites in descending order (ATRI 2010). Across the 100 sites, the average nonpeak-to-peak congestion ratio was 1.20.

The obvious benefit of avoiding congestion delays is the time savings. But is it the greatest benefit? An American Automobile Association study (Meyer 2008) does not squarely address the question posed, but does provide a perspective on the overall costs of congestion versus those of crashes. The study compared the costs of crashes to the costs of congestion (for all vehicle types) by calculating a per-person cost for crashes and multiplying it by the population figures in the same U.S. urban areas studied by TTI, as described previously. Crash costs were based on FHWA

comprehensive costs for traffic fatalities and injuries. Per capita congestion costs varied directly with city size. Per capita crash costs varied inversely with city size. Among all U.S. cities in the analysis, average per capita congestion cost (in 2005 dollars) was \$430. Per-person crash costs in those same cities was \$1,051. Thus, for the urban populations, crashes cause more than twice the economic loss (and associated harm) as does traffic congestion.

EFFICIENT SCHEDULING: OPTIMAL TIMES FOR SAFE TRAVEL

Consider the ebbs and flows of vehicle traffic within the 24 hours of each day and the 7 days of each week. Almost all of us adapt our driving patterns to those variations in traffic density in an effort to travel quickly and efficiently. The speed paradox described in chapter one suggests that when we seek smooth, fast travel, we also find relatively safe travel. This in turn suggests that evening and overnight driving would be safest because traffic is lightest at these times. A counter-argument is that night driving is inherently riskier because of driving in darkness, the greater likelihood of driver fatigue, and the greater presence of impaired motorists on the roadways. In the LTCCS, 62% of truck driver asleep-at-the-wheel crashes occurred in the 2-hour period between 4:01 a.m. and 6:00 a.m. This is well known to sleep researchers as a “circadian valley” (Knipling 2009). Alcohol use by other motorists is another major nighttime risk. One analysis found that more than one-third of fatal car–truck collisions during the overnight hours involved an alcohol-impaired car driver (Blower and Campbell 1998).

A strong majority of large-truck crashes and incidents occur during the daylight hours. Here are some percentages for daylight (including dawn and dusk) crashes and traffic conflicts:

- All 2008 police-reported crashes involving large trucks: 79%;
- 2008 fatal crashes involving large trucks: 68% (FMCSA Analysis Division 2010);
- LTCCS CT crash involvements: 73%;
- LTCCS ST crash involvements: 90%; and
- CT naturalistic driving incidents (Hickman et al. 2005): 75%.

Unfortunately, crash and incident data alone do not provide satisfactory answers to the day-versus-night question. Crash databases precisely document crash times, but they have no corresponding exposure base to serve as a denominator for generating relative crash rates by hour-of-day.

Naturalistic driving studies do provide exposure data based on onboard recordings of driving times and on randomly selected “exposure points.” In the same CT naturalistic driving data cited earlier (Hickman et al. 2005), only 59% of driving was during daylight, versus 75% of incidents. The odds ratio for incident occurrence during daylight versus darkness was

about 2.1 ($0.75 / 0.59 \div 0.25 / 0.41 \approx 2.1$), indicative of greater risk during daytime. A time-of-day function based on the same data found the lowest incident rates to occur during the overnight hours, whereas the highest were during the afternoon hours (Knipling et al. 2005).

Naturalistic driving studies may be challenged, however, based on the concept that they capture many more non-crashes (e.g., hard-braking events) and very minor crashes (e.g., curb strikes) than serious crashes. Based on a review of naturalistic driving data, crash data, and two different mileage by time-of-day exposure sources, Knipling (2009) reached the following tentative conclusions regarding large-truck crash rate by time-of-day:

- Overall, the large truck fatal crash rate per VMT appears to be roughly constant across the 24-hour day.
- Nighttime fatal crashes are more likely to involve driver fatigue or alcohol use (by other motorists), whereas daytime fatal crashes are more likely to involve traffic interaction errors.
- Nonfatal injury and property-damage-only crash risks are generally higher during the daytime hours and lower at night.
- The hours between 6:00 p.m. and 2:00 a.m. appear generally to be the safest travel times for large trucks.
- Overall crash risk rises in the early morning hours after 4:00 a.m. owing to the “one-two punch” of a circadian low period and morning rush hour traffic.

In contrast to these findings, project survey respondents strongly favored day driving over night driving. The following are the mean Likert scale ratings for questions on this topic. The seven-point Likert scale for these questions ranged from -3 (Strongly *Reduces* Fleet Safety) to +3 (Strongly *Improves* Fleet Safety).

- Maximize day driving to avoid driver fatigue and other nighttime risks:
 - Safety managers: +1.5
 - Other experts: +1.2.
- Maximize night driving to avoid daytime traffic:
 - Safety managers: -0.4
 - Other experts: -0.7.

Larger carriers are more likely to analyze their crashes in relation to exposure factors such as time-of-day. For example, case study Carriers C, D, and E all conduct such analyses. Several interviewees regarded overnight driving, particularly in the early morning hours, as more risky than day driving.

More definitive research on this issue is needed because of the contradictory findings and because of the potential safety benefits of reliable guidance on this issue. This research might include fleet-based studies in which both crash incidence and exposure can be classified by hour-of-day, or studies of free-ways or major trucking lanes.

Although its emphasis was not on traffic safety, a large urban pilot test on truck deliveries has demonstrated huge time and cost savings from shifting day deliveries to nighttime. The Research and Innovative Technology Administration–funded pilot test arranged for participating carriers to make off-hour deliveries, instead of their regular day deliveries, to retailers and other receivers in New York City. The pilot test found that off-hour deliveries increased travel speeds by up to 75% and reduced unloading times at receiver sites by about 70%. It also reported a sharp reduction in parking tickets and fines, which for daytime deliveries averaged more than \$1,000 per month per truck for participating carriers (NYC DOT 2010). The draft project report by Rensselaer Polytechnic Institute (Holguin-Veras et al. 2010) gave no comparative crash data, but suggested that crash rates are lower with off-hour deliveries. Driver *feelings* of safety may be less, however, because of their personal safety concerns about night deliveries in a large city.

AVOIDING ADVERSE WEATHER

Adverse weather is an obvious source of risk in driving and, when extreme, can be a direct cause of crashes. A U.S.DOT report (Rossetti and Johnsen 2008) argues that the role of adverse weather in truck crashes is actually increasing relative to the overall truck-crash problem. That is because weather-related fatal truck crashes have declined less slowly over the past decades than have *non*-weather-related fatal crashes. There are a large number of different weather and climate factors that can affect CMV transport safety. Some of these are listed in the textbox.

The percentage of large-truck crashes affected by adverse weather depends on the criteria used for “weather-related.” In 2008, about 15% of truck crashes occurred during rain or other “non-clear” weather condition. About 19% of fatal crashes and 22% of nonfatal crashes occurred on wet surfaces (FMCSA Analysis Division 2010). In the LTCCS, where causal factors were more closely scrutinized, 14% of truck crash involve-

Weather Effects on CMV Transport

Rain—loss of traction and control, delays

Snow and ice—delays, loss of traction and control, tire damage from chains, ice on tops of vans

Thunderstorms and tornadoes—direct damage, impaired visibility, loss of control

Temperature extremes—stresses on vehicle components, perishable cargo

High winds—vehicle instability and blowovers, especially vans

Wet pavement—loss of traction and control, road spray

Hurricanes—direct damage, road closures

Flooding—road closures, weak braking

Slides (snow, mud, rock)—collisions, delays

Source: Rossetti and Johnsen (2008).

ments had weather as an associated factor, but less than 1% of truck at-fault crashes were assigned a weather-related CR. Juxtaposing these percentages suggests that adverse weather contributes to many more crashes than it causes directly, and this was exactly the finding of a Canadian study that selected both primary and contributing crash causes (Gou et al. 1999). In that study, “slick road” was deemed the primary cause of only one of 195 truck crashes, but it was the secondary or tertiary cause of 23 crashes (12%).

Enlightened risk management requires an estimate of the relative crash risk in adverse weather or on slick roads compared to dry conditions. A 1980 NTSB report estimated the relative risk of fatal crashes on wet versus dry roads (for all vehicles) to be about four. In the LTCCS, 18% of CT crash involvements occurred on wet roads, versus 11% of ST involvements. A comparison of the LTCCS CT wet roads percentage (18%) to a naturalistic-driving wet roads exposure estimate of 9% (Hickman et al. 2005) suggests a relative risk closer to 2.

Questions 1 and 2 of both project surveys asked respondents to select the most important (Question 1) and least important (Question 2) general factors affecting truck crash risk. Overall, “weather and roadway surface conditions” was considered less important than driver characteristics (both enduring and temporary) and roadway characteristics/traffic conditions (e.g., road type). Only vehicle characteristics were rated as less important.

Another question on the surveys asked about the importance of avoiding adverse weather and slick roads. On the seven-point Likert scale from -3 (“*Reduces Fleet Safety*”) to +3 (“*Improves Fleet Safety*”), this practice was given a mean rating of +1.8 by safety managers, making it one of four top choices. The mean rating by the other experts was +1.3, fourth among 16 driving situations and practices.

FHWA is developing a Road Weather Management Program that, when completed, will provide information on current and predicted road surface and weather conditions to highway users. Information sources will include fixed road sensors and instrumented vehicles, including commercial vehicles in regular operations. Its outputs will be “decision support systems” to aid road maintainers (e.g., snow removal operations) and travelers. At this writing, the project is just beginning to determine what information motor carriers need and how best to provide that information. It is studying the economic impacts of weather on motor carriers. More information on this FHWA research and development program is available at <http://www.ops.fhwa.dot.gov/weather/index.asp>.

The *Clarus Initiative* (FHWA 2007) is a joint effort of the U.S.DOT Intelligent Transportation System (ITS) Joint Program Office and the FHWA Road Weather Management Program. The word “clarus” is Latin for clear. The Clarus Initiative is a multiyear effort to develop and demonstrate an integrated

surface transportation weather observation data management system, and to establish a partnership to create a Nationwide Surface Transportation Weather Observing and Forecasting System. State DOTs and other road operators are the program’s principal target users, though the program may provide products and services to transport companies in the future. Weather and road condition information may be provided to travelers by means of navigation and route optimization services. This would make those services more dynamic and responsive to predicted conditions.

VEHICLE SIZE AND CONFIGURATION

Large trucks come in different sizes and configurations, and are selected for their uses primarily on the basis of productivity and practicality. A logical question is whether these sizes and configurations are optimal from the safety perspective. Larger trucks might be safer if their use results in fewer trucks on the road and, therefore, less exposure to risk. Smaller trucks might be safer if they are individually less likely to be in crashes and if their crashes are less severe because of their smaller size differential compared with other vehicles. Answering this safety question is extremely difficult, however, because of several major variables confounding comparisons.

A pair of questions on both the safety-manager and other-expert survey forms asked respondents to state the general directions of their views on larger versus smaller trucks. Both questions asked for ratings on a seven-point Likert scale ranging from -3 (“*Reduces Fleet Safety*”) to +3 (“*Improves Fleet Safety*”). The two questions, intentionally worded to state opposite strategies, were:

- Use fewer, larger trucks (e.g., multitrailer trucks) when possible.
- Use more, smaller trucks (e.g., single-unit trucks) when possible.

Safety-manager respondents assigned each strategy low positive mean ratings, suggesting perhaps that either strategy could be good for safety when used appropriately. The mean ratings were +0.6 and +0.2 for the two respective items. For other experts, the two means were +0.4 and -0.3, respectively. There were wide ranges of responses for both questions for both respondent groups.

The following two subsections present statistics and evidence to help frame the issue of whether shifts in the truck size and configuration mix would enhance safety. They do not provide definitive answers, however, because of various complexities to be discussed.

Single-Unit Versus Combination-Unit Trucks

Large trucks are defined as those with gross vehicle weight ratings (GVWR) of greater than 10,000 lb; 80% to 90% of

large-truck crashes involve heavy trucks with GVWRs of greater than 26,000 lb. The two major large truck configurations are combination-unit trucks (typically tractor-semitrailers) and single-unit trucks (also called straight trucks). CTs are typically in long-haul service, whereas most STs are short-haul. STs are more numerous (6.8M versus 2.2M U.S. registrations in 2008), but on average they are driven only about one-fifth the mileage of CTs (12,362 mi per ST versus 64,764 mi per CT; FHWA 2010). As predominantly long-haul vehicles, CTs are more likely to be driven on Interstate highways and in rural areas between cities. Statistics for 2008 from the FHWA VM-1 vehicle mileage table (FHWA 2010) indicate that 49% of CT mileage was on Interstates, versus 21% for STs. The percentage of miles on rural roads (of all types) was 55% for CTs versus 43% for STs.

Most CTs are operated across state lines. This makes them, their drivers, and their carriers subject to the Federal Motor Carrier Safety Regulations (FMCSRs). Many STs are used intrastate and thus are subject only to state regulations. Many CTs are employed in multiday trips, whereas most STs are day-use vehicles, with their drivers returning home at the end of each shift. ST driving is more likely to involve regular physical activities other than driving; indeed, many STs are primarily work-support vehicles rather than cargo-delivery vehicles. These are among the operational differences making CT-ST comparisons problematic (Knipling and Bocanegra 2008).

One might automatically assume that CTs would have higher crash risks than STs because they are much larger, articulated (making them vulnerable to jackknives and more vulnerable to rollovers), and permit less visibility around the truck. Actually, overall CT crash rates are considerably lower than those of STs, probably the result of the differences in road type exposure cited earlier. However, when CT crashes occur, they are generally more severe. Table 5 presents a composite analysis of CT and ST crash rates, severities, and “bottom line” crash costs per mile based on three sources. Mileage data are from FHWA VM-1 statistics, vehicles in crashes from NHTSA (2010), and mean crash severities (expressed as cost) from Zaloshnja and Miller (2007). Because the component source statistics are from disparate sources, the derived statistics need to be considered rough estimates.

Table 5 shows the CT crash rate per VMT to be considerably lower than that of STs. CT average crash severity (average

monetized value of all crash injuries and damage), however, is considerably higher. From the crash rate and average per-crash costs, one can calculate average crash costs per mile for each vehicle type. As it turns out, the opposite-direction differences in crash rate and crash severity cancel each other out almost exactly. Derived crash costs per truck-mile are almost equal for the two vehicle types based on these sources.

An earlier study (Wang et al. 1999) used 5 years (1989–1993) of NHTSA General Estimates System crash statistics, FHWA mileage statistics, and the same approach to crash severity estimates to derive comparisons very similar to those presented previously. In the Wang study, the ST crash rate was 28% higher than the CT rate, but the CT average crash severity was 24% higher than that of STs. Average crash costs per VMT were 9.7¢ for CTs and 10.0¢ for STs. For both analyses, these costs represent the harm to all parties involved in all crashes, regardless of fault. They do not represent financial losses to carriers, which are much lower.

These crash costs-per-mile derivations might suggest that hauling freight by means of CTs has less overall risk, because CTs have much greater capacities. The same total freight could be hauled by fewer vehicles. However, the CT and ST risk statistics are based on quite different road risk exposures, because CTs are used much more on lower-risk roads. Therefore, no generalized conclusions may be drawn. Fleets may want to consider the factors in developing their risk avoidance strategies, but the decision likely comes down to their own individual operational needs.

Higher-Productivity Vehicles

The previous questions extend to the use of trucks larger than standard CTs. *Higher-productivity vehicles* (HPVs) are those with GVWRs of more than 80,000 lb, the maximum size of standard tractor-semitrailers. This report does not address the many policy and regulatory issues surrounding the use of HPVs, but will address the question from the perspective of carriers deciding how best to haul cargo within current regulations.

Longer combination vehicles (LCVs) are HPVs with more than one trailer. LCV tractors may pull two or three trailers with different configurations, subject to different restrictions. Specific LCV configurations include six-axle tractor-semitrailers,

TABLE 5
COMPOSITE ANALYSIS OF ST AND CT CRASH RATES AND COSTS

Truck Type	VMT ¹	Trucks in Crashes ²	Metric		
			Truck-Crash Involvements Per 100M VMT	Cost Per Crash ³	Crash Costs Per Truck Mile
ST	83,951 M	190,000	226.3	\$56,296	12.7¢
CT	143,507 M	190,000	132.4	\$97,574	12.9¢

Sources: ¹FHWA VM-1 Statistics; ²NHTSA (2010); ³Zaloshnja and Miller (2007). Other statistics derived.

Rocky Mountain doubles, triple-trailer combinations, and Turnpike doubles. The United States and Canada have complex sets of rules and limitations regarding use of LCVs and other HPVs. In the United States, LCVs generally are permitted in western states but not in most eastern states. A more detailed discussion of HPV configurations and rules for use is beyond the scope of this report. Individual carriers, however, often have some flexibility in the size and configurations of trucks they employ.

From a carrier perspective, the most compelling HPV rationale is efficiency. A 2008 comparative study by ATRI analyzed HPV versus conventional CT efficiency under various weight, travel, and load scenarios (ATRI 2008). In one comparison, ATRI found that moving 1,000 tons 500 mi with conventional 80,000-lb tractor-semitrailers would require 42 trips and 3,889 gal of fuel. Using a Rocky Mountain double weighing 120,000 lb would require just 27 trips, a 36% reduction, and 3,215 gal of fuel, a 17% reduction. Environmental benefits from reduced carbon emissions parallel the fuel savings. Safety benefits would arise from requiring fewer vehicles and trips to haul the same amount of freight, thus reducing exposure to crash risk. An Australian study (Moore 2007) found the HPV crash rate per freight ton-mile to be less than one-half that of regular CTs.

Two Canadian studies (Tardif and Barton 2006; Montufar et al. 2007) looked at HPVs classified as LCVs. Both concluded that LCVs offer both productivity and safety benefits if their operations are closely and intelligently controlled. The Alberta Infrastructure and Transportation study (Montufar et al. 2007) analyzed Alberta LCV crashes over a 7-year period and determined crash rates and LCV crash risk factors. They compared LCV crash rates per VMT with those of light vehicles and three other truck configurations, including standard doubles. LCVs had the lowest overall crash rate of all the vehicle types examined. This meant an even greater advantage over other truck configurations in crash rate per ton-mile, because the LCVs carried more cargo. The Tardif and Barton (2006) study reviewed the use of Turnpike Doubles in Canada. They found the Turnpike Double incident rate for seven large fleets to be 0.24 incidents per million km (equivalent to 0.39 per M VMT), compared to an overall CT rate of 0.46 incidents per million km (0.74 per M VMT). The report cited other data indicating that doubles have similar or better crash rates than tractor-semitrailers in similar operations. Both Canadian groups suggested superior driver training and qualifications as reasons behind the observed lower crash rates for HPVs compared to conventional CTs. HPV drivers tend to be more senior and have superior safety records. They generally receive higher pay than drivers of CTs in comparable operations.

HPV crashes do have higher severity potentials than those of other trucks because of their weight and number of trailers. Using LTCCS statistics, Zaloshnja and Miller (2007) found the average crash harm (including both human and material components) to be considerably higher for multi-

trailer truck crashes than for those involving one-trailer CTs. Taken together, this and the earlier studies do not permit a “bottom line” determination of the overall crash risk of HPVs relative to conventional CTs.

Earlier in this section, the results of two survey questions on the relative safety of larger versus smaller trucks were covered. The safety-manager survey also included a question on whether carriers actually used higher-capacity vehicles, and how users rated them for safety effectiveness. Only 17 of 77 respondents reported using HPVs in their fleets. User ratings of their safety effectiveness were generally high, however; the mean rating was 3.9 on a five-point scale.

Using Full Vehicle Load Capacity

Regardless of a truck’s or bus’s legal load capacity, it would appear to make sense to use the vehicle’s full capacity rather than to operate partially empty vehicles. The benefits of operating vehicles at full capacity are much like the benefits of reducing empty miles, as discussed earlier. Fully loaded trucks are less likely to experience wheel lockups and associated jackknives and other loss-of-control incidents (Moonesinghe et al. 2003; Knipling 2009). Loaded vans are less likely to be affected by crosswinds than empty ones (Rossetti and Johnsen 2008). On the other hand, heavier vehicle loads increase stopping distances (Clarke et al. 1991), thus potentially increasing rear-end and forward-collision risks. Heavier loads also raise vehicles’ centers of gravity slightly, adding to rollover risks (Moonesinghe et al. 2003). The “bottom line” probably favors full loads, though the benefits cannot be stated categorically.

ONBOARD COMPUTERS AND MOBILE COMMUNICATIONS

Commercial vehicle onboard computers and mobile communications offer a wide range of potential applications for operations and safety. Many of these applications are beyond the scope of this report. Most notably, this report does not address collision-avoidance systems, such as forward-collision warnings, lane-departure warning systems, and side object detection systems. It also does not address the technical details of onboard computers and wireless communications systems. The term *telematics* comprises onboard sensors, networks, software, GPS, and wireless communications, which are becoming commonplace in today’s commercial vehicles (Strah 2009). Much of the MCES focuses on mobile communications used to support various operational efficiencies (Belella et al. 2009). The focus here will be on those specific telematic applications mentioned by motor carriers in project surveys and interviews, which relate to both operational efficiency and safety. These were discussed primarily with regard to safety benefits, though some concerns were expressed about safety *losses* owing to driver distraction.

Commercial vehicles have been equipped with “computers” for about 2 decades, at first in the form of electronic

engine control modules. Qualcomm and other companies introduced satellite communications, which created the potential for remotely accessing onboard computer data. Cellular-based communication systems now have similar capabilities to satellite systems (Strah 2009). Current systems are becoming complex and comprehensive fleet monitoring and management tools. Telematic functionalities previously offered by third-party vendors are increasingly being offered by truck manufacturers at the time of purchase. Systems allow central, real-time viewing of a vehicle's map location, moving speed, engine speed, battery and fuel status, and trip history. Vehicle component (e.g., brake, tire) condition monitoring is also available (to be discussed in the section Monitoring Vehicle Condition). The system can be programmed to flag any trouble indicator, whether it relates to vehicle functioning or driver behavior.

A report by Aarts (2008) for the Organisation for Economic Co-operation and Development (OECD) and the International Transport Forum (ITF) describes various rapid, ongoing, efficiency-related changes in commercial vehicle technologies, logistics, and infrastructure. The report anticipates expected effects of mobile communications systems and other vehicle telematics on road transport efficiency, fuel use, pollutants, infrastructure, and safety:

The use of mobile communications tracking systems can enhance the security and efficiency of commercial vehicle operations by providing information about asset locations and a direct means of communication between carrier personnel and drivers. By closely tracking vehicles and assets, opportunities for cargo and vehicle theft can be reduced. Additional benefits include potential improvements in delivery service and asset utilization through vehicle location and routing information. Human resource management and worker productivity can be enhanced by carriers receiving more accurate status and arrival time information on shipments. Increased visibility into this information can expedite deliveries and help to ensure on-time performance to customers.

The OECD/ITF report indicated that initial cost to carriers was the principal barrier to greater market penetration of telematics, which it placed at about 35% of the European market. The FMCSA Technology Division (2010a) has published a technology product guide to wireless communications and related technologies. The guide explains much of the technology and its applications in carrier management. The product guide lists 12 system vendors.

Any discussion of in-vehicle technologies needs to consider the problem of driver distraction from such devices. Ergonomic issues relating to the safe use of telematic systems by drivers are beyond the scope of this report. Suffice it to note that driver distraction from cell phones, other in-vehicle devices, and from other sources has been recognized as a major cause of crashes. The U.S.DOT has conducted two national summits on distracted driving. Almost 1,600 U.S. companies have adopted distracted-driving policies, and a new federal law prohibits texting by commercial drivers. An FMCSA naturalistic driving study of distraction risk found that drivers interacting with a dispatching device while driving had an odds ratio of 9.9 for

incident involvement and that their eyes were off the road an average of 4.1 s/6 s of driving (FMCSA 2009).

On project surveys, respondents were asked to rate the safety benefits of using onboard computers and of using mobile communications. As with similar questions, respondents were presented with a seven-point Likert scale ranging from -3 ("*Reduces Fleet Safety*") to +3 ("*Improves Fleet Safety*"). The overall mean for safety-manager respondents with regard to onboard computers was +1.1. The mean rating for onboard communications was just +0.6, with 17 negative ratings among 78 respondents.

With regard to actual use of onboard computers, just over half of respondents used them (41 of 74). Among those who did, their mean safety effectiveness rating was 3.9 on a five-point Likert scale. For mobile communications, 58 of 78 respondents used them; users assigned a mean safety effectiveness rating of 3.6. More detailed questioning would be needed to sort out respondent views on specific benefits from these systems and on potential concerns about their use.

In the case studies, the comments of the Case Study C interviewee were pertinent to the question of driver distraction from onboard devices. The official interviewed believed that the key challenge was to communicate and provide information without causing distraction. The company does not use driver-accessible general-purpose computers in its cabs because of the potential for distraction. It does use communications and navigational aids, but without providing visual displays when vehicles are in motion. An electronic device converts any text sent to drivers to voice when the vehicle is moving so that drivers' eyes are not diverted from the road.

TEAM DRIVING

This section and the next three address topics that were not included in the original project work plan or in the safety manager surveys but have been added to the discussion because they were mentioned by carrier safety managers in project surveys (chapter three) or in interviews for the case studies (chapter four). The four topics are team driving, EOBRs, fuel economy and safety, and vehicle condition monitoring. Although each topic merits more detailed coverage, brief discussions are provided here to round out the discussion of safety-relevant carrier efficiencies.

Team driving is an efficiency practice because a team-driven long-haul truck legally can be moving almost continuously during an extended trip. One driver can rest during the other driver's driving period so that no stoppages are required by HOS rules per se. Of course, stops are still required for fuel, food, personal hygiene, and breaks away from the vehicle.

FMCSA has estimated that 9% of truck VMT is driven by team drivers. This would mean that, at any given time, about 17% of drivers are involved in team operations (FMCSA and

ICF International 2007). Team driving has several important safety advantages, but also some disadvantages. Knippling (2006, 2009) summarized the advantages and disadvantages as follows:

- Safety advantages:
 - Presence of second person in vehicle reduces unsafe driving acts;
 - Social interaction sustains alertness;
 - Reduced continuous-time driving (time-on-task);
 - Sleep and breaks can be on demand;
 - Greater regularity of sleep;
 - Greater overall sleep time; and
 - Familiar and secure sleep location.
- Safety disadvantages:
 - Poorer quality of sleep in moving vehicle;
 - Shorter durations of principal sleep period; and
 - Possible greater fatigue at start of trip (if driver sleep schedules are not coordinated).

Team driving appears to have lower crash risk than solo driving. A naturalistic driving comparison of team and solo driving (Dingus et al. 2001; FMCSA 2002) found the team driver incident rate to be less than one-half of the solo driver rate. Team drivers had far fewer driving misbehaviors such as speeding and tailgating. Although sleep quality was lower for team drivers (because they were sleeping in moving vehicles), sleep times were longer. The team driver rate of high-drowsiness incidents was just one-fourth the solo driver rate. Team drivers were much less likely to push themselves to the limit and therefore avoided high-drowsiness incidents.

Team driving presents management and operational challenges, however. Many carriers would utilize team driving more extensively if they could better meet these challenges. Questions and challenges relating to team driving involve trip planning and routing, vehicle features (i.e., sleeper berths), team driver recruiting and assignments, daily work and driving schedules (e.g., use of split sleep), and safety management practices. Married couples generally make the best and happiest driver teams because of the close driving and living conditions.

No item addressing team driving was on the safety-manager survey form, but one was added to the other-expert form. Respondents rated the item “Maximize use of driver teams for long hauls” on a –3-to-+3 Likert scale. The mean rating assigned by 31 respondents was +0.8, equal to the grand mean rating for the 16 items rated. Only one of the 11 case study interviewees explicitly mentioned team driving as a safety strategy; the Carrier B interviewee noted his company’s support for it as both a safety and efficiency measure.

ELECTRONIC ONBOARD RECORDERS

The topic of EOBRs was not within the original scope and was not included in project surveys. However, EOBRs are discussed briefly because they were cited by several case study interviewees as aids to both efficiency and safety. EOBRs

monitor commercial driver HOS compliance by maintaining a readable electronic time record of vehicle movement (driving) and of time duration since the day’s initial driving. EOBRs are used voluntarily by a growing number of CMV fleets, but are currently required only for those carriers with the worst histories of HOS noncompliance. FMCSA is considering extending the EOBR requirement to a larger percentage of noncompliant carriers. This discussion addresses only the efficiency and safety management benefits of EOBRs, not regulatory issues surrounding them.

Apart from EOBRs’ effects on HOS compliance and driver fatigue per se, they are seen by some fleets as an aid to more efficient operations and to safety management. Eight of the 11 case study carriers (see chapter four) either were using EOBRs or were transitioning to them, and most considered them beneficial for both safety and efficiency. Because EOBRs automate driver log-keeping, they save drivers’ time, streamline records and compliance management, and provide a means for safety oversight of drivers through quick identification of noncompliant drivers. EOBRs also facilitate load assignments in larger fleets by identifying drivers with sufficient time available for the loads. One corporate vice president for safety interviewed in conjunction with the study noted that EOBRs help carriers to “draw a line in the sand” in their interactions with customers. Customers might assume that paper logs allow HOS compliance flexibility, whereas EOBRs reinforce a need for absolute compliance.

Shackelford and Murray (2006) found EOBR benefits included improved fuel consumption monitoring and fuel tax compliance, quicker tabulation of driver mileage and loads, easier tracking of vehicle and engine wear, real-time vehicle location monitoring, and better communications and dispatching. The study even reported improved driver morale.

FUEL ECONOMY AND SAFETY

Another carrier efficiency factor with safety implications is fuel economy. Several interviewees believed their efforts to improve fleet fuel economy had safety benefits. Maximizing fuel economy has cost-reduction benefits for companies and the environmental benefit of reducing emissions. Devices and driving practices improving fuel economy also reduce vehicle wear, tire wear, and maintenance costs (Smith and Roberts 2007). Improved fuel economy is achieved in large part by changes in vehicle speed and driving style. These changes in turn produce safety benefits such as reduced driver stress, crash likelihood, and crash severity. Two primary approaches to improving fuel economy that have concomitant safety benefits are speed-limiting vehicles and monitoring individual driver fuel consumption.

Speed Limiters

Speed limiters, also called speed governors, are devices that limit the top powered speed of vehicles. Modern truck engines’

electronic control modules are easily programmed to limit top powered speeds to some set point. And, because “excessive speed” was the most frequent proximal cause of truck crashes in the LTCCS, some might regard speed limiters as a top-priority crash countermeasure. One must realize, however, that speed limiters cannot prevent most truck crashes arising from excessive speed. That is because most instances of “excessive speed” occur on lower-speed roads and at speeds below top freeway speeds (e.g., 65 mph). Moreover, speed limiters would not slow the downhill speeds of trucks. Speed limiters would, however, reduce both the likelihood and severity of crashes involving trucks and buses traveling at speeds greater than the top freeway speeds.

CTBSSP Synthesis 16 (Bishop et al. 2008) examined the safety impact of large-truck speed limiters. The project included a safety-manager survey based on a convenience sample, similar to the current study survey. In the MC-16 project survey, 56% of respondents indicated speed limiters were either “successful” or “very successful” in reducing crashes. Speed limiter users believed that limiters were either “successful” or “very successful” in reducing tire wear (44%) and increasing fuel economy (76%). Almost 96% of respondents believed that speed limiters had no negative effects on either their company’s safety or productivity.

Speed limiters are already required on trucks in European Union countries and in Ontario and Quebec in Canada. In the United States, NHTSA and FMCSA have proposed federal regulations for speed-limiting heavy trucks, and the matter is under rule-making consideration. Much of the trucking industry favors mandatory speed limiters on large trucks (ATA 2006), and many companies are adopting them voluntarily (Bishop et al. 2008). Reduced crashes are the primary rationale, but other reasons include lower fuel and maintenance costs, reduced emissions, and longer tire life. The project survey included no items on speed limiters, but some respondents and case study interviewees commented on their efficiency and safety value. No quantitative crash rate reductions were reported, though one earlier study accessed in the literature review found that trucking firms with firm speed limit policies had crash rates 30% lower than those of their peers (Dammen 2005).

Several of the case study interviewees stated that their trucks were electronically speed limited, usually at 65 mph. Those mentioning speed limiting also stated that they monitored driver fuel use, as discussed next.

Monitoring Driver Fuel Economy

A more direct method for improving fuel economy is to monitor fuel use for individual drivers and trips. A capability for onboard fuel consumption monitoring is commonplace in today’s trucks. Advanced, electronically controlled engines automatically monitor fuel consumption. Many EOBRs also monitor fuel consumption (Shackelford and Murray 2006).

Fuel economy can also be monitored conventionally without special onboard capabilities. Internationally, an initiative called *ecodriving* (www.ecodrive.org) is promoting greater fuel economy for all vehicles. Ecodriving focuses on driving style. Its “Five Golden Rules” are:

1. Shift up as soon as possible.
2. Maintain a steady speed.
3. Anticipate traffic flow.
4. Decelerate smoothly.
5. Check tire pressure frequently.

With the exception of Rule 1, all of the rules for improved fuel economy are also rules for safer driving. Ecodrivers are “smooth operators.” They learn to adopt a smoother driving style, “gliding” through traffic, shifting to the highest gear possible, and avoiding rapid accelerations and decelerations. Drivers learn to look down the traffic stream as far ahead as possible to predict and react smoothly to changes and interruptions in traffic flow. This defensive, anticipatory driving style also serves to reduce crash risk.

In the United Kingdom, more than 13,000 heavy vehicle operators have received *ecodriving* training, with a reported average fuel savings of 10% (SAFED 2010). Symmons and Rose (2009) described an *ecodriving* training program in a trucking fleet that reduced fuel consumption by 27%, gear changes by 29%, and brake applications by 41%. Another *ecodriving* training and monitoring program reportedly resulted in a 13% fuel savings at Setz Transport Company (IRU 2003). The Setz program involved fuel consumption monitoring, positive recognition for drivers showing improvements, and remedial training for those not showing improvement. A 2007 TRB paper (Zarkadoula et al. 2007) described a successful pilot test of *ecodriving* involving urban bus drivers in Greece. The SAFED (2010) bus and coach web page reported 12% fuel savings, a 40% reduction in gear changes, and a 60% reduction in “safety-related faults,” although the latter was not defined or explained.

The term “*ecodriving*” is commonly used in North America, but many fleets monitor fuel use for individual drivers. Fuel use may be the basis for driver rewards, positive recognition, or discipline. Many companies use the same vehicle monitoring capabilities to measure hard-braking events, which are themselves correlated with fuel consumption and crash risk. Almost all of the project case study companies (see chapter four) monitor individual driver fuel use and component behaviors such as hard braking and speeding. For example, Carrier J (Small Charter Bus Service), a small charter bus company, has equipped all of its motor coaches with a multi-function electronic monitoring system. The system provides onboard safety monitoring (OBSM) of driving behaviors and electronic HOS logs. The OBSM system records and reports top speeding time (i.e., above a specified top speed), highest observed speeds, hard-braking events and rate, fuel use, and other driving efficiency and safety indicators. The system

generates a “Driver Report Card” for each trip. The company’s safety director reported that driver acceptance of the monitoring was good and that the drivers even “make it a competition” to see who can earn the best scores.

Zuckerman (2009) described various fleet efforts to train drivers to decrease their fuel consumption, with associated safety benefits. One fleet owner interviewed identified “high acceleration and jack-rabbit starts-and-stops” as the principal targets for remediation. Minimizing speeds per se is less important than minimizing rapid accelerations and decelerations. Training and other practices suggested included:

- Use of speed limiters to eliminate the highest speeds;
- Instrument panel–mounted fuel-use displays to give drivers feedback on fuel use;
- Training drivers to resist the urge to speed up for yellow lights, but rather to anticipate light changes and coast slowly to stops;
- Use of cruise control;
- Monthly analysis of individual driver fuel use and driving patterns;
- Rather than discipline, emphasis on rewards and recognition for best performers; and
- For large fleets, extending the training and rewards up the line to fleet managers and supervisors.

No item addressing fuel economy monitoring was on the safety-manager survey form, but one was added to the other-expert form. Respondents rated the item, “Monitor fuel economy for individual drivers and provide feedback” on a –3-to-+3 Likert scale. The mean rating assigned by 31 respondents was +0.7, near the grand mean rating for the 16 items rated.

MONITORING VEHICLE CONDITION

Automatic monitoring of vehicle condition was not included in the project survey but was cited by several case study interviewees as a growing application with both safety and efficiency benefits. Mechanical maintenance deficiencies are far more common in large trucks than in light vehicles because of their larger number of components and their more continuous use. In the LTCCS, 40% of crash-involved trucks had some vehicle-related deficiency or malfunction, and the presence of such deficiencies was strongly associated with fault in crashes. Mechanical failures were much less frequently a principal cause, however. Overall, about 4% of LTCCS truck crash involvements were assigned a CR of vehicle mechanical failure, with another 2% as a result of cargo shifts.

As discussed in the section on preventive maintenance earlier in this chapter, almost all successful motor carriers practice systematic PM. By regulation, drivers are required to make pre-trip vehicle inspections each day. To supplement these measures, numerous automatic vehicle condition monitoring technologies are penetrating the fleet. These can provide continuous monitoring and feedback to drivers and recordings to

onboard electronic data recorders. Wireless transmission of vehicle condition data to roadside enforcement is an emerging capability, with potential efficiency benefits to commercial transport and safety benefits to everyone. Such monitoring can potentially include brake adjustment and condition (the most common vehicle-based problem in inspections and crashes), tires, lighting, and vehicle weight.

Tire pressure monitoring exemplifies truck vehicle condition monitoring, and is relevant to both safety and efficiency. In the LTCCS, 1.1% of at-fault truck crashes were caused primarily by tire failure. The percentage was much higher for STs (2.2%) than for CTs (0.7%; Knipling and Bocanegra 2008). Poor tire condition is the second most common vehicle source (behind brakes) of violations in truck roadside inspections. Many of these crashes and violations could be avoided by proper tire care and regular inspection. The most common cause of tire failure is underinflated tires, which can become overheated and have excessive sidewall flexing (Freund et al. 2006; Knipling 2009). A 2003 study of large-truck tire inflation (Kreeb et al. 2003) found that many fleet operators do not perform the regular tire pressure maintenance recommended by tire manufacturers. The study reported that:

- Approximately 7% of CMV tires tested were under-inflated by 20 psi or more.
- Only 44% of tires were within 5 psi of their specified target pressure.
- Tire-related costs were the single largest maintenance expense for CMV fleets, averaging about 2¢ per mile or about \$2,500 for an annual 125,000-mile operation.
- Improper inflation raised total tire-related costs by \$600 to \$800 annually per tractor-trailer combination.
- Improper tire inflation increased annual procurement costs for new and retreaded tires by 10% to 13%.
- Larger fleets are generally more systematic and rigorous than smaller fleets with regard to tire pressure and other tire maintenance.

An FMCSA safety technology product guide, available on its website, describes various types of tire pressure monitoring systems (TPMS) available from nearly 20 vendors (FMCSA Technology Division 2010b). These devices also save pre-trip inspection time, improving operational efficiency. Flanigan (2010) reported that approximately 5% of fleets use TPMS. The small system penetration was said to be the result of fleet concerns about system reliability, maintenance costs, and initial costs. This situation may be changing rapidly, however. In *Transport Topics*, Reiskin (2010) reported a survey of managers of large U.S. fleets finding that 43% use TPMS. Widespread use of TPMS by large fleets may portend greater penetration across all fleets.

Challenges associated with the use of TPMS include proper training for maintenance staff, consistent and correct use of data from the systems, and disciplined inspections and tracking of the sensor systems themselves to ensure that they do not

add to overall vehicle maintenance workload (Van Order et al. 2009). A recently published fleet test of onboard brake performance and tire pressure sensors (Van Order et al. 2009; Flanagan 2010) used three different TPMS on 36 tractors and 39 trailers in two fleets. Preliminary results from one fleet and 4.6 million miles of travel found the use of TPMS to be associated with slower tire wear and 1.8% better fuel economy. Complete and final project results are pending at this writing.

GENERAL RELATIONSHIP BETWEEN EFFICIENCY AND SAFETY

The previous sections have presented findings relating to specific tactics to increase both carrier efficiency and safety. What about the *general* relationship between efficiency and safety? In the aggregate, do the various practices cited previously add to both greater efficiency and greater safety? Do the same carrier practices and processes that foster efficient operations also foster safe operations? The project did not *measure* either the efficiency or safety of any fleet, so it cannot provide definitive evidence. A question on both the safety-manager and other-expert survey forms, however, asked respondents about the general relationship. High majorities of both categories of respondents selected the choice, “Highly efficient carriers tend also to be *more safe* than other carriers.” Only 2 of 77 safety managers believed that such carriers were *less safe*. None of the 31 other-expert respondents selected this choice.

In an article entitled “High-Performance Work Systems and Occupational Safety,” Zacharatos et al. (2005) surveyed 138 manufacturers (including chemical, automotive, and construction) that were members of the Industrial Accident Prevention Association of Ontario. The surveys contained 124 Likert-scale questions on high-performance management practices and the extent to which employees practiced and were

committed to high performance. Two companies participated in more in-depth surveys of individual frontline industrial supervisors. “Generic” high-performance management practices were associated with both company financial performance and with safety measures. Figure 5 shows some of the correlational relationships among various corporate measures. Of most interest here is the relationship between a corporate high-performance work system and corporate safety climate.

Striving for high organizational performance may have negative impacts on safety if it results in excessive demands for productivity. Efforts to increase productivity in factories, for example, can result in higher accident rates if workers are performing tasks too fast for safety (Blum and Naylor 1968). Caird and Kline (2004) looked at job demands and driver safety behaviors among 150 work drivers in a large western Canadian company. The study found that organizational demands encouraging high work speed were associated with higher levels of driver fatigue, more errors, and more moving violations.

Larger carriers have advantages over smaller companies and owner-operators in creating operational efficiencies with potential safety implications. Many proactive and systematic management practices are practiced more widely among larger carriers than among smaller ones (Stock 2001; Corsi and Barnard 2003). Larger companies may also feel less pressure to push productivity and delivery schedules to unsafe levels. In Australia, Mayhew and Quinlan (2006) interviewed 300 long-haul commercial drivers to assess economic pressure, driver workload, and occupational safety and health. Owner-operators reported worse health and safety than did drivers in small fleets and, especially, those in large fleets. Structured interviews revealed a connection between economic pressure (e.g., month-to-month dependence on income from loads) and negative health and safety outcomes. Owner-

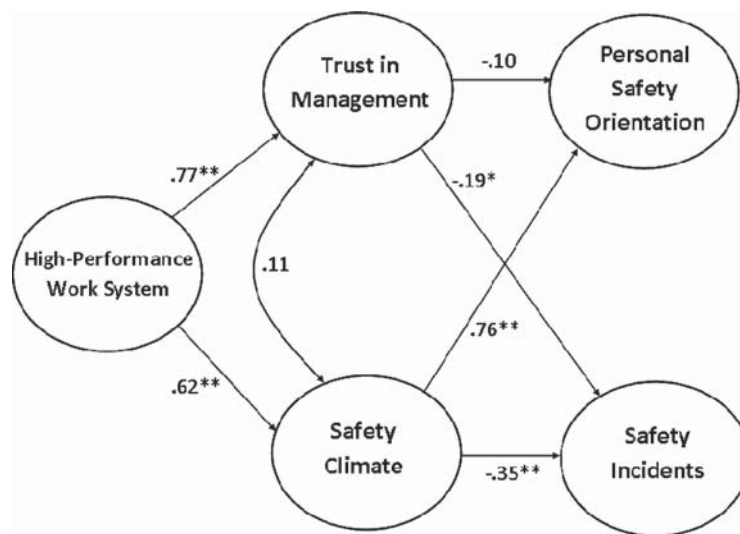


FIGURE 5 Interrelationships among five organizational characteristics among 138 industrial manufacturing organizations. Source: Zacharatos et al. (2005).

operators were less likely to seek medical treatment for injuries or illnesses, often citing financial pressures as the reason. Drivers working for large firms felt more secure about reporting sickness and injuries and in taking time off for them.

Can one therefore demonstrate a link between overall motor carrier performance and safety? Corsi et al. (2002) compared the *financial* performance of 656 carriers with their safety performance to determine whether there was a link. The study controlled for carrier features such as size, revenues, average load, and average haul. Financial data were obtained from the ATA corporate annual report database, and carrier safety ratings were retrieved from SafeStat. The 656 companies in the study were mostly large, prominent carriers. Carriers with satisfactory ratings (553 of the 656) had an average 3% profit margin. The 103 companies not rated satisfactory (96 conditional + 7 unsatisfactory) had average operating *losses* of 4%. On a second financial measure, return on investment (ROI), satisfactory fleets had a 5% average ROI. This compared to a *negative 2%* ROI for non-satisfactory (conditional or unsatisfactory) fleets. Though there were exceptions, safer companies generally had higher profits. The study contained no measure of efficiency per se, but the findings of this large study with regard to safety and profitability suggest a similar link between safety and efficiency.

The following are safety-manager survey comments relating to ways in which efficiency can relate to safety, positively or negatively:

- You must develop a safety culture from the top down. You must be willing to make investments in technology to promote safety.

- Executive and management involved in all levels of safety and compliance.
- Accountability for safety.
- No one practice but a culture.
- Efficiency and safety must be used in conjunction, and not considered “stand-alone” initiatives.

The following are similar comments from other experts:

- Managers of well-managed operations pay attention to all aspects of their operations.
- Some efficiency measures in dispatch may result in non-rested drivers being given long runs that will result in fatigue.
- Some standard practices with respect to vehicle type, operations, and schedules may promote efficiencies but not fit a driver’s ergonomic needs, circadian rhythm, and temperament, which often lead to increased risk.
- Need to adopt a systems-based approach, applying a model or framework such as the Haddon Matrix.
- To manage efficiency implies an organizational structure that can also manage risk.

Two of the case study interviewees commented on the general issue of operational efficiency in relation to safety. Carrier A’s management structure is designed to strengthen the link between efficiency and safety. Division operational managers are also safety managers for their divisions and are evaluated based on both operational and safety success. Carrier J’s safety manager had had previous experience in pickup and delivery (P&D) operations. He felt that intense monitoring of driver delivery times by management sometimes forced drivers to work too fast and cut corners on safety.

SURVEY METHODS AND RESULTS

Chapter two reviewed research and trade literature on relevant principles and specific practices relating to carrier operational efficiency and safety. An additional method for obtaining information for this study was project surveys. Two similar survey forms were used for two different respondent groups. Most important was a survey of current CMV fleet safety managers. The safety-manager survey asked respondents their opinions on safety effects of operational practices, what practices they used, and their ratings of their effectiveness. Of secondary importance, but still of interest, was a survey of other experts in motor carrier safety. This survey form addressed the same general topics, but was limited to opinions because the respondents were not current practitioners. The two survey forms are provided in Appendix A. This chapter describes the survey approach and specific methods, and provides principal results for each respondent group. Results for the two respondent groups are presented separately because of their different perspectives on the problem, and because the two forms differed somewhat in their questioning approaches and in specific content.

A general caveat regarding most of the survey responses is that they represent subjective responses to subjective questions. A few questions were objective (e.g., questions asking safety managers whether or not they use a particular safety management practice), but most called for subjective judgments by respondents. Another caveat is that both samples must be regarded as convenience samples of interested, knowledgeable individuals, not as representative samples of larger populations. Conceptually, both the safety-manager and other-expert populations are amorphous and are not captured by any list. In addition, the safety-manager population is extremely large (in the hundreds of thousands in the United States), diverse, and problematic from the sampling perspective.

OVERVIEW OF SURVEY APPROACH, ANALYSIS, AND INTERPRETATION

Sampling Approach

The conceptual *population* for the safety-manager survey was North American motor carrier (truck and bus) safety managers. This population is somewhat amorphous, as there is no consistent definition or criterion for “carrier safety manager.” Also, there is no central potential respondent list that could be used as the basis for systematic sampling or as a source for

accurate respondent contact information likely to result in a satisfactory survey return rate.

The safety-manager *sample* consisted of individuals participating in trade associations or national meetings relating to motor carrier safety. The e-mail addresses of these individuals were known to the project team, or paper survey forms were distributed directly to them in trade association meetings. The sample is presumed here to be strongly biased toward organizations and individuals with more experience, past success, safety sophistication, and safety conscientiousness than the overall population.

Those returning the survey (whose responses are presented here) are the *respondents*. Just as the sample space was likely a biased slice of the population, the sample was likely a biased slice of the sample space. That is because in most surveys, those responding tend to be more committed and interested in the topic than those not responding. Moreover, they tend to be more educated and verbal (Walonick 2010). Both sources of bias almost certainly operated, and operated strongly, in the present safety-manager survey and, perhaps to a lesser extent, in the other-expert survey.

A larger study focusing on the survey per se likely could do a better job of capturing the larger population, increasing the size and representativeness of the sample space, and obtaining a higher survey response rate. Study resources did not permit a more extensive, rigorous, and layered subject sampling approach. The obtained sample, even if representing a skewed sample of the most knowledgeable and safety-conscious respondents, still provided valuable information, however, for the following reasons:

- It tapped the views and practices of industry leaders.
- It provided information on the subjects’ *relative* opinions on the various operational risk factors and practices presented.
- It provided contacts for follow-up interviews with safety managers regarding the practices of safety-active companies.

Data Analysis and Interpretation

There were three general types of questions on the surveys: questions about respondent *opinions*, questions about *specific carrier practices* (safety managers only), and questions about

respondents themselves and their organizations. Opinion questions were subjective and called for subjective, judgmental responses, mostly in the form of Likert scale ratings. These responses should not be misinterpreted as objective facts. Questions about specific carrier practices asked for yes–no answers and, when the answer was “yes,” asked for an effectiveness rating on a Likert scale. These were on the safety-manager survey forms only. Questions about the respondents themselves (e.g., years of experience) were also objective. All of the caveats discussed earlier regarding sample representativeness apply to all questions on both forms. Thus, none of the survey results on either form can be generalized to larger respondent groups or populations such as “North American carrier safety managers” or “experts in motor carrier safety.” The value of the survey results is not based on representativeness to larger populations, but rather on the respondents’ answers to specific questions relative to other, similar questions. For example, which operational factors are most associated (positively or negatively) with risk? Which specific operational practices were rated as most safety-effective?

Non-Use of Response Percentages

Per CTBSSP policy, the survey results tables in this chapter, and survey results cited elsewhere in this report, do not include results percentages. Instead, raw numbers are cited (e.g., “42 of 51 respondents . . .”). This practice reduces the likelihood that survey results will be misinterpreted or incorrectly cited as representing larger respondent populations. Readers may generate their own percentages, but they should not be reported as being representative of larger groups.

Likert Scale Means

Likert scales are numeric rating scales, often with five choices numbered from 1 to 5. Likert scales usually have word descriptors for each choice, or “anchor” choices at the ends and perhaps the middle. Two different Likert scales were used in the project surveys:

- A seven-point scale relating driving situations and operational practices to crash risk. Choices ranged from “reduces fleet safety (–3)” to “improves fleet safety (+3).”
- A five-point scale rating the safety effectiveness of carrier operational practices. Choices ranged from “highly ineffective (1)” to “highly effective (5).” Some pairs of questions were intentionally constructed to present opposite strategies.

Results are provided here in the form of respondent counts for each choice, along with the weighted arithmetic mean of all choices. Median responses are also provided for the seven-point scale items. TRB’s online survey service provided these

statistics automatically in survey reports. For paper surveys, the survey statistics were obtained from Excel spreadsheets used to enter and reduce the data.

MOTOR CARRIER SAFETY-MANAGER SURVEY METHODS

This section describes methods specific to the safety-manager surveys. Safety managers were the respondent group of greatest interest for the study. These individuals have company titles such as safety manager, safety director, director of compliance, and vice president for safety (and/or compliance). A few have titles relating to operations. The respondent pool (sample space) consisted of individuals participating in national industry groups supporting safety, or who had attended safety meetings and whose contact information was available to the project team. As discussed in the previous section, the respondent pool may be characterized as representing safety-conscious carrier safety or operational managers who are willing to participate in such research. All of the sampling and data analysis issues discussed previously apply to the safety-manager survey.

Questionnaire Design and Content

The safety-manager survey questionnaire consisted of the following general sections:

- A brief statement of the study and survey purpose, with a confidentiality assurance.
- Two related five-choice questions on general factors affecting safety and crash risk (used in the paper form only). These questions were omitted from the survey form to help increase the response rate.
- Fifteen driving situations or operational practices, each rated on a –3-to+3 Likert scale (–3, –2, –1, 0, +1, +2, +3) for effect on fleet safety. Negative values were for “reduces fleet safety,” whereas positive values were for “improves fleet safety.” One item (item 9) was omitted from the bus version because it was not applicable to bus operations.
- Eleven carrier operational practices and tools, with a two-part answer for each:
 - Yes–no for whether the practice was used by the manager’s fleet; and
 - If yes, a 1–5 Likert scale to rate the practice’s safety effectiveness.

One item (item 21) was omitted from the bus version because it was not applicable to bus operations.

- A single four-choice question on the general relation between carrier efficiency and safety.
- An open-response question asking what operational efficiency or practice contributed most to fleet safety.
- An open-response question asking for any other comments.

- Four questions on respondent's professional experience and fleet characteristics.
- A space to provide an optional e-mail address to which to send the project report PDF.

Questionnaire Distribution and Analysis

Two commercial motor vehicle trade associations, the Truckload Carriers Association and the Bus Industry Safety Council, assisted the study by distributing paper survey forms (both for this project and MC-22) at national meetings. A third association, the NPTC, assisted the effort by e-mailing the online survey solicitation to its Safety Council members, with the council's endorsement.

Paper surveys were formatted on a single front-and-back sheet where answer choices were to be circled or penciled in. At the Truckload Carriers Association meeting, approximately 100 survey forms (for each of the two projects) were distributed, and 24 were returned. Two other truck forms were obtained through personal contacts. At the Bus Industry Safety Council meeting, approximately 50 forms were distributed, and 30 were returned. At the latter meeting, attendees included a significant proportion of non-safety managers (e.g., government officials, trade association officials, vendors, and consultants) for whom the survey was not intended. The exact number of carrier safety managers in the room is not known.

An additional effort to obtain safety-manager respondents was made using TRB's online survey service. The online survey had the same content as the paper survey, except for the omission of the first two questions relating to general crash-risk factors. These two questions were somewhat wordy "thought questions," requiring more time for response than others on the survey. They were omitted from the online version to streamline the survey and perhaps increase response rates.

E-mail requests were sent to 130 respondents believed to be current motor carrier safety managers based on their business cards and contact information gathered at various recent motor carrier safety conferences. An additional solicitation was sent from an NPTC official to NPTC Safety Council members. Twenty-five people took the online version of the survey. This brought the total safety-manager survey sample to 79 (24 + 30 + 25).

Paper survey answers were entered into an Excel spreadsheet for analysis. Online survey tabulations were generated and added to the Excel sheet totals.

The earlier experience suggests that both methods are viable. Handing out paper surveys at trade association meetings with the support of the organizers likely yields a higher return than does e-mail solicitation. Carrier officials are the targets of a lot of product marketing and other promotions, and thus may tend to be wary of responding to external e-mails in general. Potential respondents may have confidentiality concerns, even if confidentiality statements are prominent in

survey materials. Walonick (2010) provides a more extensive discussion of the difficulties of obtaining survey data from various respondent groups. According to one report (cited in McQuire 2010), only about half of e-mails are opened. This highlights the difficulty of obtaining high response rates from e-mailed surveys.

In spite of the challenges of obtaining a robust survey sample and the acknowledged unrepresentativeness of the sample in relation to all safety managers, the 79 responses did provide sufficient data for analysis as well as many useful comments. In addition, a number of respondents volunteered for follow-up structured interviews, described here.

Follow-Up Structured Interviews

The last question of the MC-23 (*Driver Selection Tests and Measurements*; Knipling et al. 2001) safety-manager survey form asked respondents if they would be interested in participating in a paid follow-up interview to discuss innovative fleet practices. The question included the assurance, "Responses will be confidential; no interviewees or carriers will be identified unless desired." The key purpose of the interviews was to gather information and opinions for project case study write-ups (see chapter four). If respondents did volunteer, and had a relatively large number of "yes" responses under carrier practices for both surveys (MC-22 and MC-23), they were contacted to schedule an interview (covering both MC-22 and MC-23 topics). Altogether, 20 respondents were contacted, usually both by e-mail and by phone. Apparently, most had second thoughts because only 10 agreed to participate. These 10, however, provided substantial information on carrier operational practices relating to safety. One other carrier was added through personal contact. Thus, 11 case studies are provided in chapter four.

MOTOR CARRIER SAFETY-MANAGER SURVEY RESULTS

Factors Affecting Safety and Crash Risk

Questions 1 and 2 addressed factors affecting safety and crash risk. These were also the first two questions of the MC-23 survey, as the two questions were pertinent to both studies. The same five choices were presented in each. Question 1 asked for the respondent's choice of *up to two* factors having the *greatest* effect, whereas Question 2 asked for the *one* factor with the *least* effect. Table 6 presents responses.

As expected, choices for the two opposite questions (greatest and least) were more or less inversely related. Driver-related choices (a) and (b) were regarded as having the greatest effect on crash risk. The vehicle-related choice (c) received the fewest "most" votes, whereas (d) "Roadway characteristics and traffic conditions," received the greatest number of "least" votes. Thus, both (c) and (d) could be regarded as "losers." Ironically, perhaps, choice (d) has the greatest relevance to the current study, because many operational transport efficien-

TABLE 6
SAFETY-MANAGER RESPONSES RELATING TO FACTORS AFFECTING SAFETY AND CRASH RISK

(1) Factors Affecting Safety and Crash Risk: Consider the entire fleet of North American commercial vehicles (trucks and buses). Across all these drivers and vehicles, which factors have the greatest association with crash risk? Pick up to two of the factors below which, in your opinion, have the greatest association with crash risk. (2) In your opinion, which one factor has the least association with crash risk?	(1) Most	(2) Least
(a) Enduring/long-term driver traits; e.g., age, physical abilities, medical conditions, personality, behavioral history.	31	5
(b) Temporary driver states; e.g., moods, daily circadian rhythms, effects of recent sleep, effects of recent food & fluids, effects of environmental conditions in cab, etc.	32	4
(c) Vehicle characteristics (e.g., configuration, safety equipment, load) & mechanical condition (e.g., brakes, tires).	7	12
(d) Roadway characteristics & traffic conditions; e.g., undivided vs. divided highways, construction zones, traffic density, speed limits, lane restrictions, etc.	10	14
(e) Weather and roadway surface conditions; e.g., wet vs. dry, road surface friction, visibility, wind, etc.	9	8
Total Responses:	89	43

cies are related to roadway and routing choices. Other choices may also be relevant to specific operational practices. Figure 6 shows the “most” vote tallies graphically.

Driving Situations and Operational Practices Possibly Affecting Fleet Safety

Questions 3 to 17 presented 16 driving situations and operational practices, preceded by the following general instructions:

The following are driving situations or carrier operational practices which may *reduce*, *not affect*, or *improve* fleet safety. Assign each situation or practice a negative value if it decreases safety, zero if it does not affect safety, or a positive value if it improves safety. Choose one number for each. Consecutive items may represent alternative or even opposing safety strategies.

A seven-point Likert rating scale was used for responses, ranging from -3 (reduces fleet safety) through 0 (no effect on safety) to +3 (improves fleet safety). “X” was given as a choice for “no opinion/not sure.” Table 7 provides the 15 items, the number of ratings for each of the eight choices (-3, -2, -1, 0, +1, +2, +3, X) plus the total number of responses (N), the median (Md) and the arithmetic average (Avg), also known as the mean. Median ratings are provided along with mean ratings because of the large number of choices (7) and because extreme choices might shift means unduly. Question 9 was omitted from the bus version of the survey because it was not considered relevant to bus transport, owing to the relative inflexibility of bus schedules. Thus, the number of responses to this question was lower and applied only to truck transport.

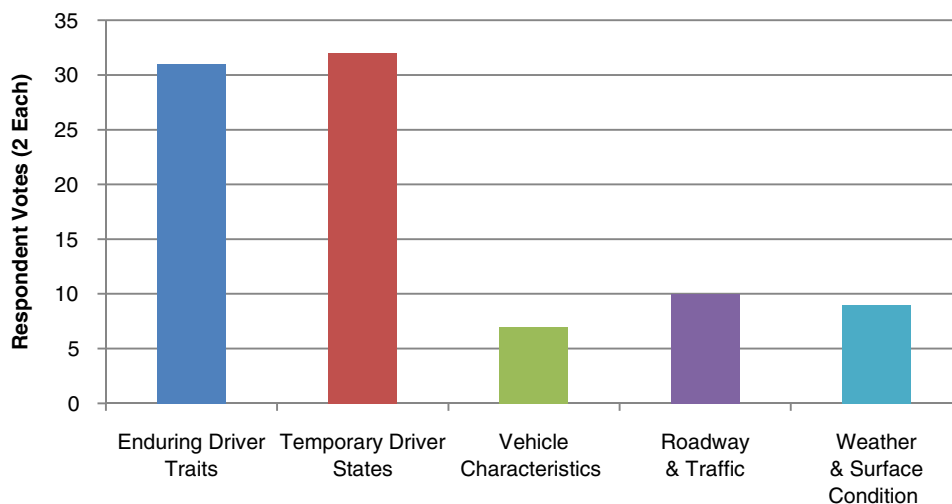


FIGURE 6 Factors affecting crash risk.

TABLE 7
SAFETY-MANAGER RATINGS OF DRIVING SITUATIONS AND OPERATIONAL PRACTICES

Driving Situation/Operational Practice:	-3	-2	-1	0	+1	+2	+3	X	N	Md	Avg.
(3) Reduce empty backhauls (deadheads)	0	2	5	35	14	12	3	7	78	0	+0.5
(4) Reduce loading/unloading delays	0	0	1	8	18	25	19	7	78	+2	+1.8
(5) Increase routing efficiency using GPS navigation aids and/or truck routing software	0	1	0	3	20	37	13	3	77	+2	+1.8
(6) Maximize travel on Interstates and other freeways	0	0	2	4	18	34	17	2	77	+2	+1.8
(7) Maximize travel on low-speed roads (e.g., two-lane local roads)	10	21	30	4	5	3	2	2	77	-1	-1.1
(8) Maximize day driving to avoid driver fatigue & other nighttime risks	0	1	3	8	25	23	17	1	78	+2	+1.5
(9) Maximize night driving to avoid daytime traffic [truck data only]	3	7	16	4	14	4	0	1	49	0	-0.4
(10) Avoid urban rush hours and other heavy traffic situations	1	1	0	4	21	27	19	3	76	+2	+1.7
(11) Avoid adverse weather and slick roads	1	1	2	2	16	33	23	0	78	+2	+1.8
(12) Avoid construction zones	1	1	1	4	32	29	9	1	78	+1	+1.4
(13) Assign familiar routes to drivers when possible	0	2	2	7	15	29	22	0	77	+2	+1.7
(14) Use fewer, larger trucks (e.g., multi-trailer trucks) when possible	1	4	8	25	13	10	8	8	77	0	+0.6
(15) Use more, smaller trucks (e.g., single-unit trucks) when possible	3	2	9	32	14	8	1	9	78	0	+0.2
(16) Use onboard computers	1	0	6	17	18	18	11	7	78	+1	+1.1
(17) Use mobile communication systems	3	5	9	16	15	15	9	6	78	+1	+0.6
Grand Mean:											+1.0

Avg. = Arithmetic average (mean); Md = Median (middle); N = Number of respondents.

Four practices received the highest mean ratings: (4) reducing loading and unloading delays, (5) increasing routing efficiency, (6) maximizing travel on Interstates, and (11) avoiding adverse weather. Closely following were (10) avoiding urban rush hours and (13) assigning familiar routes to drivers. The practice receiving the highest negative rating was (7) maximizing travel on low-speed roads, followed by (9) maximizing night driving. The highest rating variabilities were seen on the two items relating to truck size (14 and 15). Both received votes for all seven Likert scale ratings, suggesting a great deal of disagreement on this issue. Figure 7 shows graphically the 16 items in ascending order by mean rating.

Operational Practices and Tools Used by Fleets

Questions 18 to 28 presented 11 carrier practices and first asked respondents to state whether or not they regularly used the practice (yes or no). Respondents answering “yes” on a question were then to rate the effectiveness of the practice on a five-point Likert scale. The specific instructions were as follows:

For each of the operational practices below, please indicate **yes** or **no** whether your organization uses the practice. If **yes**, rate its overall **safety effectiveness** using the 1–5 scale provided. Circle your answer. If **no**, leave the ratings blank.

The five Likert scale choices were:

1. Highly Ineffective;
2. Ineffective;
3. Not Sure/Neutral;
4. Effective; and
5. Highly Effective.

Table 8 provides the number of respondents who reported using each practice.

Table 9 shows the effectiveness ratings given by users of the practice. Statistics provided include the number for each Likert scale choice, the total number of responses (N), and the weighted arithmetic average or mean of responses (Avg.). Averages are rounded to the nearest tenth. Respondents used

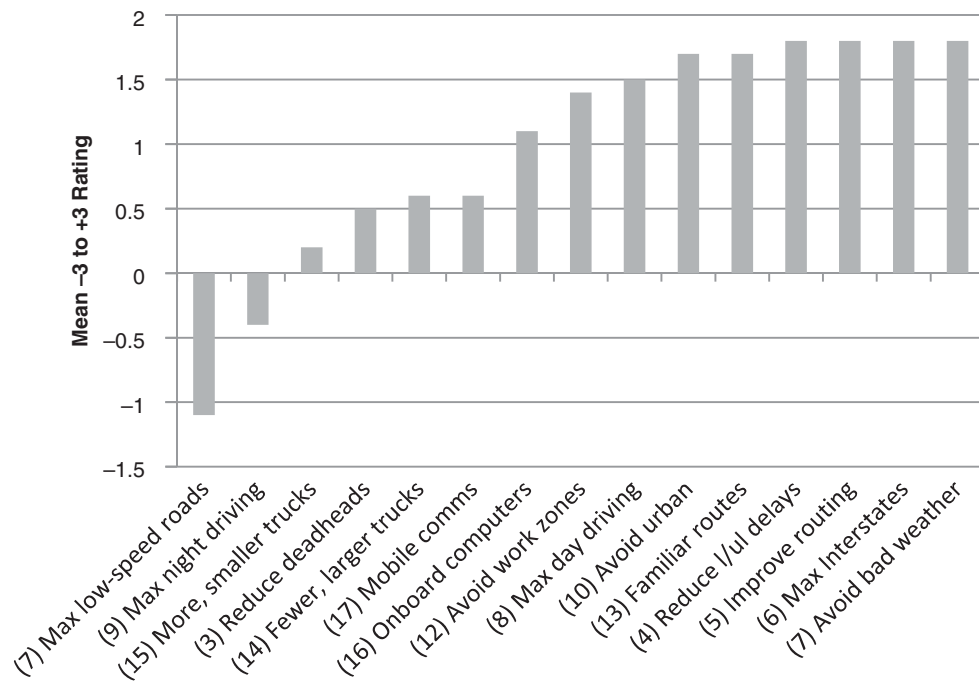


FIGURE 7 Fifteen driving situations and operational practices, rank-ordered by safety-manager mean safety rating.

TABLE 8
SAFETY-MANAGER RESPONDENT USE OF OPERATIONAL PRACTICE/TOOL

Operational Practice/Tool:	Rating or Statistic:		
	Yes	No	N
(18) Preventive maintenance (PM) schedule and record for each vehicle	77	2	79
(19) Preventive maintenance software or spreadsheets	62	16	78
(20) Use brokers or other services to reduce empty backhauls (deadheads)	30	47	77
(21) Charge extra fees to customers for excessive loading/unloading delays	34	16	50
(22) Require drivers to complete a trip plan prior to trip	24	53	77
(23) Use general GPS navigation/routing systems or services	42	34	76
(24) Use truck-specific navigation/routing systems or services	29	48	77
(25) Provide EZ Pass™ transponder and/or reimbursement of toll charges to drivers/owner-operators	66	12	78
(26) Use higher capacity vehicles (e.g., twin trailers, LCVs) when possible	17	60	77
(27) Use onboard computers	41	33	74
(28) Use mobile communications	58	20	78

N = number of respondents.

TABLE 9
SAFETY-MANAGER LIKERT SCALE RATINGS OF EFFECTIVENESS OF OPERATIONAL PRACTICE/TOOL

Operational Practice/Tool	Rating or Statistic					N	Avg.
	1	2	3	4	5		
(18) Preventive maintenance schedule and record for each vehicle	4	1	2	33	35	75	4.3
(19) Preventive maintenance software or spreadsheets	2	0	11	32	14	59	3.9
(20) Use brokers or other services to reduce empty backhauls (deadheads)	1	7	14	8	1	31	3.0
(21) Charge extra fees to customers for excessive loading/unloading delays	2	1	14	18	0	35	3.4
(22) Require drivers to complete a trip plan prior to trip	0	2	4	14	5	25	3.9
(23) Use general GPS navigation/routing systems or services	1	2	10	24	4	41	3.7
(24) Use truck-specific navigation/routing systems or services	1	1	5	17	5	29	3.8
(25) Provide "EZ Pass" transponder and/or reimbursement of toll charges to drivers/OOs	1	0	22	26	14	63	3.8
(26) Use higher capacity vehicles (e.g., twin trailers, LCVs) when possible	0	1	3	10	3	17	3.9
(27) Use onboard computers	1	1	9	17	9	37	3.9
(28) Use mobile communications	0	3	22	23	8	56	3.6
Grand Mean:							3.7

an average of 6.1 of the 11 practices listed. The most frequently used were PM schedules and records for each vehicle, providing "EZ Pass" and toll reimbursements to drivers, and using PM software or spreadsheets. The least frequent practice was the use of higher-capacity vehicles. Other practices used by a minority of respondents were requiring drivers to complete trip plans and using truck-specific GPS navigation aids.

Almost all 11 of the practices received favorable ratings of safety effectiveness. Only item (20), "Using brokers or other services to reduce empty backhauls," received a neutral mean

rating (3.0 on the 1-to-5 scale). The 10 other practices received mean ratings in a relatively narrow range between 3.4 and 4.3. Item 18, "Preventive maintenance schedule and record for each vehicle," received the highest overall rating (4.3).

Additional Questions

Question 29 asked respondents about the general relationship between carrier efficiency and safety. Table 10 presents the question stem, response choices, and number for each.

TABLE 10
GENERAL RELATION BETWEEN CARRIER EFFICIENCY AND SAFETY FOR SAFETY MANAGERS

(29) What is the relationship between carrier efficiency and safety? Circle the letter of the statement you most agree with.	N
(a) Highly efficient carriers tend also to be more safe than other carriers.	63
(b) Carrier efficiency and carrier safety are largely unrelated to each other.	8
(c) Highly efficient carriers tend to be less safe than other carriers.	2
(d) Don't know/no general opinion.	4
Total:	77

A strong 63 of 77 respondents believed that highly efficient carriers also tended to be safe carriers. Only 2 of 77 respondents thought the association was negative.

Question 30 asked respondents to write in the operational efficiency or other practice contributing *most* to fleet safety. Because this was an open-response item, responses varied and not all respondents answered the question. Many of the responses did not relate specifically to report topics. Others did relate directly or partially to carrier efficiencies addressed in this report. Here are the responses:

- Preventative maintenance and/or pre- posttrip inspections [eight respondents]
- Driver training from a new hire to refresher training with a trainer riding along to observe and comment; “comprehensive” driver training; other training-related [five respondents]
- Onboard computers [three respondents]
- Incentive/safety bonus program [two respondents]
- You must develop a safety culture from the top down. You must be willing to make investments in technology to promote safety.
- Executive and management involved in all levels of safety and compliance
- We are a fleet of all owner-operators. Communication is the key to our efficiency and assists us in being a safe and efficient heavy haul company.
- Conducting a thorough pre- and post-trip inspection
- Reduction of speed
- Participation of the drivers in programs aimed at safety
- Driver debriefing and communication
- Insistence on daily management monitoring of pre- and post-trip inspections
- Onboard camera system
- Help locations with route development to ensure HOS compliance, and onboard e-logs. Also, quarterly drivers’ meetings and Smith System Advanced Driver Training
- Using technology but the driver remains in control of the vehicle
- Effective, engaged management on-site, interaction with drivers and showing true caring for their well-being goes far with our drivers, more than electronics or computers.
- Accountability for safety
- Governed truck speeds
- No one practice but a culture
- Driver and maintenance staff input
- Speed reduction and driver wellness programs
- Ten-point safety and productivity incentive plan with quarterly review and cash incentive for each driver
- Keeping up with driver logs—rest times and keeping drivers on similar shifts, especially regarding time off-duty
- Operational efficiency means “well run,” not “get the load there on time or else.”
- Prudent use of fleet and deadhead moves

Question 31 asked for other comments regarding carrier efficiencies or other practices affecting fleet safety positively or negatively. These comments were similar to those noted above. Here are the responses:

- Training, training, more training
- Insistence on pre-trip inspections before loading to include on-board knuckle boom crane [for off-loading and field loading of heavy cargo] pre-trip
- Inefficiencies of shipper/receivers in the loading and unloading process have the most negative effect on safety for our drivers.
- Efficiency and safety must be used in conjunction, and not considered “stand-alone” initiatives.
- Our biggest challenge is with our customers and suppliers. There is ignorance or apathy toward an efficient loading or unloading process.
- Electronic logs may be able to help with logbook falsification, which would help with the safety issue.
- Comprehensive driver wellness program, detailed audit of HOS have had very positive impact on safety.
- Ongoing training, the daily presence of safety personnel advocating safety
- Need a safety person present in operations to provide positive safety influence daily
- Drivers appreciate efforts to reduce fatigue and improve time driving.
- Strong oversight of operations
- Periodic retraining of drivers, regular safety meetings, follow-up on PMs, meet with mechanics each week and go over work orders for past and current week
- Driver training and supervision
- Long-term core values should drive decisions, not short-term “firefighting;” focus on prevention, not reaction.
- Central operations environment helps control the excess movement of fleet.
- Efficient scheduling and routing contributes to safe operations.

Information About Respondents and Their Fleets

Safety managers were also asked two questions about their professional experience and two questions about their fleet’s characteristics. Question 32 asked their years of experience as a safety manager or human resource manager, and Question 33 asked their total years of experience in commercial truck or bus operations. Table 11 provides summary statistics of their answers.

Altogether, the 79 safety-manager respondents claimed 989 years’ experience as safety managers and 1,821 years total experience in CMV transport. As a group, they are highly experienced.

Question 34 asked respondents to state the approximate number of power units (i.e., tractors or trucks) currently in

TABLE 11
SUMMARY STATISTICS ON PROFESSIONAL EXPERIENCE OF
SAFETY-MANAGER RESPONDENTS

Question	Statistic			
	Range	Median	Mean	StDev
(32) Number of years experience as carrier Safety Manager or Human Resource Manager	2 to 45	10	13.2	9.1
(33) Total years experience in commercial truck/bus operations	5 to 62	22	24.0	12.6

Note: StDev = standard deviation.

their fleets. Table 12 provides summary statistics of their answers.

There are no definitive population statistics to compare with the previously cited respondent individual and fleet statistics. Nevertheless, it is clear that survey respondents generally were more experienced than most individuals with motor carrier safety management responsibilities, and that their fleets were generally much larger than average. This reflects the trend of larger fleets being overrepresented at virtually all national and regional safety conferences, and as active members of national and state truck and bus transport organizations.

Question 35 asked respondents to select the truck or bus operation type that best characterized their fleet. The numbers of responses in each category are listed in Table 13. Although the question asked for “the” best characterization, many bus safety managers selected two choices (“g” and “h” in Table 13). Therefore, that dual selection is listed later as a separate choice.

OTHER-EXPERT SURVEY METHODS

The secondary project survey was of other experts in motor carrier safety. These individuals were primarily professional associates of the principal project investigators. They were known personally or through their jobs or other professional activities. They included professionals in government, industry trade associations, other industry roles (e.g., safety consulting), and research. Many of these individuals are actively involved in other TRB truck and bus safety activities. Even though these individuals are highly knowledgeable, they are regarded as secondary respondents because they are (by definition) not currently carrier practitioners. Their survey forms

included opinion items, but no items on their operational practices, because they are not so involved. The data from this other-expert survey were of interest, although, as it (1) gauges expert opinion on questions, (2) points toward areas perhaps deserving more consideration, and (3) is a way of identifying ongoing research relating to project topics.

Questionnaire Design and Content

The other-expert survey questionnaire was similar to that for safety managers. It consisted of the following general sections:

- A brief statement of the study and survey purpose, with a confidentiality assurance;
- Two related five-choice questions on general factors affecting safety and crash risk (used on paper form only);
- 16 driving situations or operational practices, each rated on a –3-to-+3 Likert scale (–3, –2, –1, 0, +1, +2, +3) for effect on fleet safety;
- A multiple choice question on the general relationship between carrier efficiency and safety;
- An open “comments” space; and
- Two questions on respondent’s years of motor carrier safety-related experience and on specific types of positions held.

Questionnaire Distribution and Analysis

The other-expert survey was administered only online through TRB’s online survey service. The survey solicitation was sent by means of e-mail to 134 individuals, with a second e-mail reminder sent several weeks later. A total of 32 online surveys

TABLE 12
SUMMARY STATISTICS ON SAFETY-MANAGER RESPONDENT FLEET SIZE

Question	Statistic			
	Range	Median	Mean	SD
(34) Approximate number of power units currently in fleet	14 to 15,000	112.5	866	2,201

TABLE 13
SAFETY-MANAGER RESPONDENTS' FLEET
OPERATION TYPES

Operation Type	No. Safety Managers
(a) For hire: long haul/truckload	21
(b) For hire: long haul/less-than-truckload (LTL)	2
(c) For hire: local/short haul (most trips < 100 miles)	2
(d) Private industry: long haul	6
(e) Private industry: local/short haul (< 100 miles)	10
(f) Passenger carrier: scheduled service	4
(g) Passenger carrier: charter	15
(g+h) Passenger carrier: both scheduled service and charter	10
(h) "Other" (mostly variations of above types)	3
Total (N):	73

were completed (24%). Survey results were tabulated by the reports program.

OTHER-EXPERT SURVEY RESULTS

Factors Affecting Safety and Crash Risk

Questions 1 and 2 addressed factors affecting safety and crash risk. The same five choices were presented in each. Question 1 asked for the respondent's choice of up to two factors having the greatest effect, whereas Question 2 asked for the one factor with the least effect. Table 14 presents responses. As expected, choices for the two opposite questions (greatest and least) were more or less inversely related. Driver-related

choices (a) and (b) were regarded as having the greatest effect on crash risk, whereas vehicle-related choice (c) was regarded as having the least. Choice (d) has the greatest overall relevance to the current study, because many operational transport efficiencies are related to roadway and routing choices. Other choices may also be relevant to specific operational practices.

This respondent group considered temporary driver states (b) to be the strongest factor affecting crash risk. Roadway characteristics and traffic conditions, the choice most relevant to the current study, was third in the "most" voting and fourth in the "least" voting. Thus, relative to safety managers, other experts considered choice (d) to be relatively more important.

Driving Situations and Operational Practices Possibly Affecting Fleet Safety

Questions 3 to 18 were preceded by the following general instructions:

The following are driving situations or carrier operational practices which may *reduce*, *not affect*, or *improve* fleet safety. Assign each situation or practice a negative value if it decreases safety, zero if it does not affect safety, or a positive value if it improves safety. Choose one number for each. Consecutive items may represent alternative or even opposing safety strategies.

A seven-point Likert rating scale was used for responses, ranging from -3 (reduces fleet safety) through 0 (no effect on safety) to +3 (improves fleet safety). "X" was given as a choice for "no opinion/not sure." Table 15 provides the 16 items, the number of ratings for each of the eight choices (-3, -2, -1, 0, +1, +2, +3, X), as well as the total number of

TABLE 14
OTHER-EXPERT RESPONSES RELATING TO FACTORS AFFECTING SAFETY AND CRASH RISK

(1) Factors Affecting Safety and Crash Risk: Consider the entire fleet of North American commercial vehicles (trucks and buses). Across all these drivers and vehicles, which factors have the greatest association with crash risk? Pick up to two of the factors below which, in your opinion, have the greatest association with crash risk. (2) In your opinion, which one factor has the least association with crash risk?	(1) Most	(2) Least
(a) Enduring/long-term driver traits; e.g., age, physical abilities, medical conditions, personality, behavioral history	14	7
(b) Temporary driver states; e.g., moods, daily circadian rhythms, effects of recent sleep, effects of recent food & fluids, effects of environmental conditions in cab, etc.	25	0
(c) Vehicle characteristics (e.g., configuration, safety equipment, load) & mechanical condition (e.g., brakes, tires)	7	12
(d) Roadway characteristics & traffic conditions; e.g., undivided vs. divided highways, construction zones, traffic density, speed limits, lane restrictions, etc.	10	3
(e) Weather and roadway surface conditions; e.g., wet vs. dry, road surface friction, visibility, wind, etc.	2	9
Total Responses:	58	31

TABLE 15
OTHER-EXPERT RATINGS OF DRIVING SITUATIONS AND OPERATIONAL PRACTICES

Driving Situation/Operational Practice:	-3	-2	-1	0	+1	+2	+3	<i>N</i>	<i>Md</i>	<i>Avg.</i>
(3) Perform regular vehicle preventive maintenance	0	0	0	0	10	8	13	31	+2	+2.1
(4) Use brokers or other services to reduce empty backhauls (deadheads)	2	0	4	19	4	2	0	29	0	-0.1
(5) Reduce loading/unloading delays	0	2	0	2	15	5	7	31	+1	+1.4
(6) Increase routing efficiency using GPS navigation aids and/or truck routing software and websites	0	0	0	7	18	3	3	31	+1	+1.1
(7) Maximize travel on Interstates & other freeways	0	0	0	2	12	9	8	31	+2	+1.7
(8) Maximize travel on low-speed roads (e.g., two-lane local roads)	6	11	10	3	1	0	0	31	-2	-1.6
(9) Maximize day driving to avoid driver fatigue & other nighttime risks	0	1	1	5	11	11	2	31	+1	+1.2
(10) Maximize night driving to avoid daytime traffic	1	7	12	7	2	2	0	31	-1	-0.7
(11) Avoid urban rush hours and other heavy traffic situations	0	0	3	4	14	5	5	31	+1	+1.2
(12) Avoid adverse weather and slick roads	1	0	1	3	12	11	3	31	+1	+1.3
(13) Avoid construction zones	0	1	0	4	14	8	4	32	+1	+1.3
(14) Assign familiar routes to drivers when possible	0	0	0	2	13	10	6	31	+2	+1.6
(15) Use fewer, larger trucks (e.g., multi-trailer trucks) when possible	2	1	4	9	7	5	3	31	0	+0.4
(16) Use more, smaller trucks (e.g., single-unit trucks) when possible	3	2	6	13	6	0	1	31	0	-0.3
(17) Maximize use of driver teams for long hauls	1	0	1	7	18	2	2	31	+1	+0.8
(18) Monitor fuel economy for individual drivers and provide feedback	0	0	1	12	13	4	1	31	+1	+0.7
Grand Mean:										+0.8

Avg. = Arithmetic average (mean); *Md* = Median (middle); *N* = Number of respondents.

responses (*N*), the median (*Md*) and the arithmetic average (*Avg.*), also known as the mean. Median ratings are provided along with mean ratings because of the large number of choices (seven), and because extreme choices might shift means unduly. Note also that Questions 17 (on driver teams) and 18 (on fuel economy monitoring) had no corresponding questions on the safety-manager version of the survey.

The practices with the highest mean ratings for these respondents were preventive maintenance (item 3, +2.1), maximizing travel on Interstates and freeways (item 7, +1.7), and assigning familiar routes to drivers (item 14, +1.6). Those rated overall as detrimental to safety included travel on low-speed roadways (item 8, -1.6) and night driving (item 10, -0.7). Notice

the spread of answers for Questions 15 and 16 regarding truck size, indicating a wide range of opinions.

Additional Questions

Question 20 asked respondents about the general relationship between carrier efficiency and safety. Table 16 presents the question stem, response choices, and number for each. A strong majority of respondents (26 of 31) believed that efficient carriers were also safe carriers.

Question 19 asked respondents to write in other comments regarding carrier efficiencies or other practices that affect fleet

TABLE 16
GENERAL RELATIONSHIP BETWEEN CARRIER EFFICIENCY AND SAFETY
FOR OTHER EXPERTS

(29) What is the relationship between carrier efficiency and safety? Circle the letter of the statement you most agree with.	<i>N</i>
(a) Highly efficient carriers tend also to be more safe than other carriers.	26
(b) Carrier efficiency and carrier safety are largely unrelated to each other.	2
(c) Highly efficient carriers tend to be less safe than other carriers.	0
(d) Don't know/no general opinion.	3
Total:	31

safety positively or negatively. It added, "For example, what carrier efficiencies affecting safety (positively or negatively) have we missed?" The following are selected responses:

- Management safety attitude; pressure by brokers; drivers not being responsible on their time off and resting.
- Managers of well-managed operations pay attention to all aspects of their operations.
- The biggest single determinant of overall safety is risk exposure. Interstates, because they are divided trafficways with no at-grade intersections are 400% safer than U.S. and state routes. More than 70% of fatal truck crashes occur on these latter roads, not Interstates where all the enforcement attention and focus takes place. Carriers operating mostly on non-Interstate roads are much more at-risk than those that predominantly travel up and down Interstates.
- Driver monitoring with feedback on lane deviations and hard-braking events.
- Intermixing passenger vehicles and heavy vehicles on two-lane freeways, especially with rolling terrain and significant speed differentials.
- Some efficiency measures in dispatch may result in non-rested drivers being given long runs that will result in fatigue.
- Some standard practices with respect to vehicle type, operations, and schedules may promote efficiencies but not fit a driver's ergonomic needs, circadian rhythm, and temperament, which often leads to increased risk.
- Driver training programs.
- Onboard monitoring of driving behavior so safety managers can provide feedback and incentives to increase safety.
- Some survey questions are too simplistic in what is a complex set of interdependencies.
- Need to adopt a systems-based approach, applying a model or framework such as the Haddon Matrix.
- Using automated, tamper-resistant monitoring of HOS compliance would affect safety positively and also maximize efficiency.

- To manage efficiency implies an organizational structure that can also manage risk.

Information About Respondents

The years of motor carrier safety experience of the 32 other-expert respondents, addressed by Question 21, ranged widely from 5 years to 40 years. The mean was 19.3 years. These respondents were also asked in Question 22 to indicate their professional experience areas relating to motor carrier safety. The breakdown is shown in Table 17. The percentages shown sum to well over 100%, because most respondents gave multiple responses. The results show that the experience base of the other experts was both extensive and varied, with heavy representation of individuals with backgrounds in government, industry trade associations, safety consulting, accident investigation and data analysis, and motor carrier safety research.

TABLE 17
OTHER-EXPERT RESPONDENT EXPERIENCE AREAS

Experience Area:	No.
(a) Government enforcement	7
(b) Other government (e.g., rulemaking, policy)	15
(c) Industry trade association	8
(d) Commercial driver	5
(e) Carrier safety director/manager	3
(f) Other carrier management position	3
(g) Safety consultant or vendor to fleets	7
(h) Accident investigation/data analysis	15
(i) Motor carrier safety research	17
(j) Journalist	0
(k) Driver trainer/training development	4
(l) Insurance for motor carriers	2
(m) Other	3
Average Number of Experience Areas/Respondent	2.8

CASE STUDIES

The 11 carrier case studies in this chapter are based on phone or in-person interviews with motor carrier safety managers or other carrier officials with similar job titles and responsibilities. Most companies and interviewees were identified through the project safety-manager surveys, although some were already known to the report authors. Interviewees were selected based on the number and variety of their carriers' innovative operational practices as indicated on their survey forms.

The Sampling Approach section in chapter three described the interview process and listed some supplemental questions asked as follow-ups to the respondents' written survey responses. As noted there, interviewees were recruited from the survey questionnaires; respondents were asked if they wished also to participate in a phone interview on innovative carrier practices. Each interview followed the same general topic sequence, but specific questions varied in response to interviewee answers and carrier practices discussed. The case studies summarize interviewee answers and highlight operational practices believed to be safety-effective by each carrier. Interview data were supplemented by a review of the carriers' website content relating to its operations and practices. Companies are identified only as "Carrier A," "Carrier B," and so on.

The 11 companies interviewed included large fleets (>1,000 vehicles), medium fleets (100–1,000 vehicles), and small fleets (<100 vehicles). They are further classified as follows:

- Large for-hire truckload carriers (A–D);
- Medium for-hire truckload carriers (E–F);
- Large private truck fleets (G–H);
- Medium private truck fleet (I); and
- Small bus fleets (J–K).

The authors believe that all of the carriers included here are well-run operations with excellent safety programs. Nevertheless, project resources did not permit formal evaluation of any operational practice of any carrier. The examples given are to be considered as suggested practices for consideration by readers, not as scientifically proven methods.

For consistency, all interviewees are termed safety managers or safety directors, regardless of their actual job titles. Each case study includes a textbox with five notable carrier efficiencies with likely safety benefits. Practices were chosen for the textboxes based on the SMs' enthusiasm for them, and to present the widest possible range of worthwhile practices.

Note also that, within each case study, qualitative statements made (e.g., regarding operational risk factors or practices to reduce risk) reflect the opinions of the SM interviewee and not necessarily the conclusions of this report.

CASE STUDY A: LARGE TRUCKLOAD CARRIER

Carrier A is a large truckload carrier providing refrigerated, flatbed, and tanker services. Its safety director has decades of experience in carrier safety and operations, and is active in several national truck safety-related organizations. In the project survey, the safety director rated the following operational practices as having the greatest benefits to safety:

- Reducing loading and unloading delays;
- Maximizing travel on Interstates and other freeways;
- Avoiding urban rush hours and other heavy traffic situations;
- Avoiding adverse weather and slick roads;
- Avoiding construction zones; and
- Assigning familiar routes to drivers when possible.

The safety director believed that efficient carriers tended to be safer carriers because of "a thousand little things." Inefficient carriers "let things go," such as postponing PMs or not replacing old equipment. Company A replaces its trucks after approximately 3 years of service, which reduces mechanical problems with possible safety effects.

The company's website says it provides computerized mapping and routing directions "to driver associates to ensure that loads get from point A to point B in the quickest, safest and most efficient manner. The greatest benefit of this technology is reducing the time driver associates spend searching for shippers' docks, especially in remote locations or congested industrial areas." This technology also reduces driver cell phone use and provides a delivery tracking system.

Division operational managers are considered to be safety managers as well, and this is incorporated into their performance evaluations. This concept strengthens the link between operational efficiency and safety. The company uses commercial software to plan and manage their PMs. Trucks are equipped with EOBRs, though the safety director stated that they *decrease* productivity by 3% to 5%. EOBRs do, however, provide operational managers with better data on

**Five Carrier A
Innovative Operational Practices**

- Commercial software for PM scheduling and records
- Computerized maps and route directions provided to drivers for trips
- Division operational managers also responsible for safety
- Speed-limits trucks to 65 mph and monitors fuel use
- “Aggressive” enforcement of detention fees for delays

driver hours and compliance, which in turn improves planning and dispatching.

Carrier A speed-limits its trucks to 65 mph and tracks driver and trip fuel economy. Lowering speeds and monitoring fuel consumption has increased its average fuel economy from 5 to 7 mpg. This is primarily an economy initiative, but it also has safety benefits. Similarly, the company’s trucks have automatic tire pressure monitoring and inflation. The main motivation is fuel savings, but it reduces tire wear and associated tire failures.

To reduce loading and unloading delays, the company negotiates an agreement with each shipper and receiver regarding acceptable load and unload times. Typically, on-schedule trucks must be turned around within 2 hours of their arrival at the customer yard. Detention fees are charged for delays of more than 2 hours, with the money going directly to contract drivers. Carrier A’s safety director believed that “aggressive” enforcement of these agreements was essential for reducing excessive delays and their negative safety consequences.

CASE STUDY B: LARGE TRUCKLOAD CARRIER

Carrier B is a large refrigerated trucking company, hauling temperature-sensitive freight such as fresh produce, meat, dairy products, beverages, and chemicals. The company has national operations of several types. The SM respondent and interviewee worked in the company’s truckload operation. In addition to various specific risk avoidance practices, Carrier B employs a comprehensive safety management system in its operations. This analytic system, provided under contract by a safety consulting firm, tracks about “3,000 data points” relating to drivers, equipment, locations, and various other operational risk factors. For example, the system looks at each freight “lane” (standard route; e.g., Chicago to New York) to assess its efficiency and safety relative to other lanes. Subpar performance by any company division or terminal is diagnosed quantitatively and brought to management’s attention. Analysis of company truck crash rate by time-of-day has indicated a 15% to 20% higher rate during the early morning hours between 2:00 a.m. and 6:00 a.m.

In the project survey, the SM rated the following operational practices as having the greatest benefits to safety:

- Reducing loading and unloading delays;
- Maximizing travel on Interstates and other freeways;
- Maximizing day driving to avoid driver fatigue;
- Avoiding adverse weather and slick roads;
- Use of onboard computers; and
- Use of mobile communication systems.

Carrier B takes advantage of its size and also employs brokers to minimize its empty backhaul (deadhead) rate. In 2009, the company attained a 10% deadhead rate, which the SM considered to be a major accomplishment. A realistic goal for more companies is 15% to 20%, in the SM’s view.

Trucks are equipped with a variety of advanced equipment, including EOBRs, fuel consumption monitoring, satellite tracking, and mobile communications. EOBRs reduce the “guess work” in HOS compliance monitoring and schedule planning. The SM estimated the daily driver time savings from EOBR use to be 30 min—time that can translate into more rest and safer travel. Fuel economy monitoring produces direct cost savings and also reveals driver habits and degree of compliance with company guidelines.

The company’s website advertises that many dedicated routes are available for experienced company drivers. These are run by a separate division of the company. For drivers, the advantages of dedicated runs include a stable income and predictable home times. Dedicated routes also promote safety through work–rest schedule regularity and through driver familiarity with roadways and traffic patterns. Team driving is also supported within the company, both for its more efficient use of equipment and for its acknowledged safety advantages.

CASE STUDY C: LARGE TRUCKLOAD CARRIER

Carrier C is a large, diversified carrier with primarily truckload operations but also with intermodal and logistics services. The company’s truckload business is itself diverse, including long-haul, regional, expedited, dedicated, and bulk operations. The SM interviewee is a corporate senior vice president who oversees safety, security, and driver training. The interviewee is active in national trucking and safety organizations and in 2010 was awarded a Distinguished Safety Leadership Award

**Five Carrier B
Innovative Operational Practices**

- Quantitative safety management system evaluates multiple risk factors and exposures.
- Uses brokers and other methods to reduce deadhead rate to 10%
- EOBR use estimated to save drivers 30 min per day
- Teams used when possible for both efficiency and safety
- Dedicated routes available to some drivers

by the Truck Safety Coalition, a partnership of truck safety advocacy organizations.

Of 15 operational practices rated in the project survey, the SM rated maximizing travel on Interstates and other freeways as most benefiting fleet safety. Other routing and scheduling practices rated highly included maximizing day driving, assigning familiar routes, and avoiding urban traffic and construction zones.

This carrier uses nine of the 11 operational practices and tools probed in the project survey. This includes use of PM schedules and software, brokers and other methods to reduce empty backhauls, detention fees for loading and unloading delays, and a requirement that drivers prepare trip plans before driving. The SM noted that detention fees are necessary because, without them, customers have little incentive to reduce delays. Drivers are paid by the mile and delays have a low perceived cost to customers, posing an efficiency and safety challenge to the supply chain.

With regard to onboard computers and communications, the SM believed that the key challenge was in providing information and communications without increasing driver distraction. The company does not use general-purpose computers in its cabs because their potential for distraction is too great. It does use communications and navigational aids, but without providing visual displays when vehicles are in motion. Displays automatically go blank and are locked out-of-use when vehicles are in motion. The routing interface converts text to voice when the vehicle is moving. The company's routing software uses a zip-code-center-to-zip-code-center routing algorithm to identify the miles associated with a given load run by the shortest route. Minimizing the out-of-route mileage by this metric is one component of a quarterly driver pay bonus system. The company is considering improvements to this approach by giving greater weight to travel efficiency and safety (e.g., by routing through Interstates even if distances are longer).

The carrier conducts extensive and probing analyses of its safety risk factors and crash causes. The SM regarded driving in construction zones as among the most important conditions elevating crash risk. The company has "dramatically higher" crash rates in construction zones than in other settings. The SM believes this to be the result of two factors: mis-engineering of the zones and, more importantly, car drivers trying to pass trucks and cut in front of them before a zone. Schedule factors associated with severe crashes include time-of-day, hours since last break, and day of the work cycle. The SM would like to be able to factor crash risk into company pricing models so that the costs of transporting goods under higher-risk conditions are passed along to customers demanding such services.

The company is equipping many of its new trucks with automated transmissions to make them easier to operate and to reduce driver distraction from shifting gears. "Automated"

Five Carrier C Innovative Operational Practices

- Detention fees for excessive loading and unloading delays
- Routing communications provided only when vehicle is stationary
- Extensive crash and exposure analyses have identified risky conditions such as work zones.
- Many trucks equipped with automated transmissions for ease-of-use and safety
- Electronic monitoring of vehicle movements with automatic messages sent to drivers nearing HOS limits

transmissions are not fully automatic, but they require much less shifting skill, attention, and work than a truck manual transmission (Knipling 2009). The safety rationale is that reducing driver physical and mental workload from shifting will permit greater and more continuous attention to driving. The company conducted an experiment in which a group of new drivers was trained and fielded with automated transmission vehicles, whereas a control group used standard gears. New drivers using automated transmissions had slightly increased fuel use, but this was more than offset by a 26% lower first-year crash rate than that of the control group. They also completed their training sooner on average, and had a 35% higher 1-year retention rate (Knipling 2009).

The carrier's trucks are electronically monitored to track driver work and driving times, and those driven by employee drivers are speed-limited. Electronic work time monitoring starts with the automatically detected first movement of the vehicle on a driver's tour-of-duty. The system is programmed to assume that the driver's on-duty period started 30 min earlier. If a driver has not shut down well within HOS limits, the system sends him or her update messages on approaching time limits. The system tabulates the number of messages sent to each driver, along with the driver's daily and weekly miles.

CASE STUDY D: LARGE TRUCKLOAD CARRIER

Carrier D is a large common and contract carrier specializing in truckload quantities of general commodities. The company is located in the central United States and runs primarily medium-distance dry van and flatbed hauls. In the project survey, Carrier D's SM rated the following operational practices as having the greatest benefits to safety:

- Maximizing travel on Interstates and other freeways;
- Maximizing day driving;
- Avoiding urban peak hours and other heavy traffic situations;
- Avoiding adverse weather and slick roads;
- Avoiding construction zones; and
- Assigning familiar routes to drivers when possible.

Carrier D has a systematic, software-based PM program that schedules each truck for about 2 hours of PM every 20,000 miles of travel. This is supplemented by remote electronic monitoring of engine performance. The company does not provide GPS routing systems free to drivers, but does sell them to drivers for a discounted price. These systems have truck-specific routing information. The SM told of two incidents of mishaps involving truck drivers using general-driving GPS navigation systems. In one, a truck driver followed GPS directions under a low-clearance bridge, resulting in a crash. In the other, a driver followed GPS directions down a narrow dirt road and rolled the truck. Assigning drivers dedicated runs when possible is another way to reduce driving on unfamiliar roads.

Remote monitoring of trucks through wireless communications includes fuel economy monitoring. A general, company-wide, and driver-specific goal is 6 mpg. Although the primary motivation was economic, the SM believed that the monitoring had safety benefits as well. The same “patterns of behavior” and care while driving were reflected in both high fuel economy and low-risk driving. The same system monitors driver hard-braking and roll-stability-related events.

Carrier D does not use EOBRs for HOS compliance, but the SM believed that their use would be an operational and safety enhancement. This view was based more on potential safety management benefits of EOBRs than on their HOS compliance and fatigue reduction benefits per se. EOBRs would give the carrier safety department more knowledge of operations, help to make better use of available driver hours, and quickly highlight compliance problems. They would reduce driver fatigue and drowsiness as well, but “that wouldn’t be my sales pitch” in arguing for their use.

Carrier D analyzes its operations extensively; for example, it closely examines and compares safety and productivity data on its many individual fleets (divisions). It has the capability to conduct relative crash risk analyses of operational factors such as time-of-day, day-of-week, month-of-year, and driving location. A limitation of such analyses, in the view of the SM, is that there is usually not enough operational flexibility to apply lessons learned fully.

Five Carrier D Innovative Operational Practices

- Performs PM on each truck every 20,000 mi (2- to 3-month intervals)
- Provides truck-specific GPS routing system to drivers (at discounted price)
- Assigns drivers dedicated runs when possible
- Monitors individual driver fuel economy with goal of 6 mpg
- Charges detention fees for excessive loading and unloading delays

CASE STUDY E: MEDIUM-SIZED REGIONAL TRUCKLOAD CARRIER

Carrier E is a medium-sized truckload carrier in eastern Canada. The company owns several hundred tractors and more than 1,000 trailers. The company offers logistics and warehousing services in addition to truckload haulage. Truckload capabilities include refrigeration and Hazmat. Most runs are regional trips of less than 500 miles (one way) between Ontario and the northeastern United States, or in the upper Midwest.

The company recently received International Standards Organization (ISO) certification under Standard ISO 9001:2008 encompassing its transportation, warehousing, and logistics operations. The company also received the Shipper’s Choice Award from *Canadian Transportation & Logistics* magazine, based on a poll of shippers. Evaluation areas for the award include “On Time Performance,” “Equipment and Operations,” “Information Technology,” “Competitive Pricing,” “Customer Service,” “Problem Solving,” and “Value-Added Services.”

Carrier E participates in a consortium of 18 Canadian motor carriers striving to improve their safety and reduce losses. The group meets quarterly to share best safety practices and materials, including those related to operational efficiencies. Carrier E’s 5 years of participation in this group has resulted in steady declines in the company’s loss ratios.

Just over half of Carrier E’s runs are out-and-back trips to two U.S. states. Because of the predictability of its runs, Carrier E is able to book back-haul loads for a high percentage of its trips. Their current empty truck rate is 12%. This low rate benefits both efficiency and safety, and has enabled the company to pay drivers by the mile equally for full and empty trips. Paying drivers for empty trips eliminates a possible source of driver unhappiness, stress, and schedule pressure.

Carrier E has its own truck maintenance facility and manages preventive maintenance using *TRANSMAN*® software. The company owns many more trailers than tractors, so trailers can easily be scheduled for regular maintenance.

Carrier E is equipping its new trucks with EOBRs and transitioning to E-logs. The SM is enthusiastic about this change. E-logs “get rid of paper” and improve real-time management of operations. Drivers like the E-logs, and their use positions the company to deal better with CSA 2010. The company’s HOS compliance was already high with paper logs, so EOBRs’ benefits are from “easier compliance, not better compliance.”

The SM believed that the company’s communications system was an important element in operational safety. The system facilitates trip pre-planning (required for every trip) and efficient deployment of drivers and vehicles. The system does not provide continuous navigation guidance to drivers,

**Five Carrier E
Innovative Operational Practices**

- Participation in safety consortium of 18 motor carriers
- Reduction of empty truck rate to 12%. Drivers are paid for empty trips.
- Commercial software for PM planning and record-keeping
- Transitioning to EOBRs for “easier compliance”
- Satellite truck tracking and communications

but drivers may access *PC*MILER*® directions on their truck units when needed. The system also monitors vehicle speeds and hard braking, though Carrier E does not emphasize the onboard monitoring aspects. Instead, the company talks to drivers directly about their driving behaviors and seeks to intervene if drivers appear under undue operational or personal stress.

CASE STUDY F: MEDIUM-SIZED TRUCKLOAD CARRIER WITH HAZMAT OPERATIONS

Carrier F is a truckload carrier primarily serving the Midwest and eastern United States. The company has several hundred trucks and hauls both Hazmat and non-Hazmat cargo. Its website states that its performance and safety follow International Standards Organization (ISO) processes. The ISO approach includes regular statistical process analysis, including both internal and external audits. Per its website, the company’s safety culture is “by the book,” but also strives to exceed regulatory requirements. The company’s safety director, interviewed for this project and case study, was recently recognized as “Safety Director of the Year” by the Missouri Motor Carriers Association.

In the project survey, the SM rated the following operational practices as having the greatest benefits to safety:

- Increasing routing efficiency using navigation aids;
- Maximizing travel on Interstates and other freeways;
- Maximizing day driving;
- Avoiding urban rush hours and other heavy traffic situations;
- Assigning familiar routes to drivers when possible; and
- Using mobile communications.

With regard to day versus night driving, the SM noted that both have inherent risks and crash threats. For day driving it is other traffic, and for night driving it is driver fatigue. Evenings between 6:00 p.m. and midnight were regarded as an optimal time period. Driving after midnight was not encouraged, and drivers were urged to stop for rest whenever they were tired. Operations require some driving during the overnight hours, however.

**Five Carrier F
Innovative Operational Practices**

- ISO process analysis
- Load planning with driver and delivery schedule matching
- Satellite tracking and communications
- Truck-specific GPS navigation aids
- Detention fees for excessive delays

Carrier F emphasizes load and schedule planning and truck tracking. It uses commercial software to match drivers to shipments based on driver HOS status and load requirements. Every truck and shipment is tracked by means of satellite communications. Brokers are employed to reduce empty backhauls. The company charges detention fees to shippers and receivers for excessive loading and unloading delays. The company provides truck-specific GPS navigation systems to its drivers. The SM noted, however, that even truck-specific GPS routing may not always be optimal or legal. The shortest route, for example, may be slower and riskier. Trip planning and driver judgment and experience were still critical for efficient operations.

Carrier F has equipped some of its trucks with EOBRs and is moving to equip more. Benefits are primarily from efficient management, not from HOS compliance per se. EOBRs enable a “better fit” within HOS constraints. EOBR drivers actually get more miles because they are more efficient. Carrier F monitors individual driver fuel use, motivated primarily by cost savings.

CASE STUDY G: LARGE RETAIL CHAIN PRIVATE FLEET

Carrier G is the private fleet serving a large, national retail chain store. The company is actually served both by its private fleet and for-hire carriers. The safety manager interviewed is the national manager of safety and compliance for the private fleet, which consists of regional divisions. Each division makes local (<100-mile) and regional (>100-mile) deliveries within its area. The SM’s job responsibilities encompass qualifications and safety, operations, and risk analysis and control. Carrier G is a recent recipient of the American Trucking Associations (ATA) President’s Award for Best Overall Safety Program for fleets in its size category. It has also been recognized for its low crash rate and low driver-injury rate.

Carrier G uses two different truck-routing programs (*Roadshow* and *Trucks*) to optimize both its truck routing and delivery schedules. Routing factors in the products being shipped, their package size (“cube”), and delivery time windows for the stores being served. The software considers traffic characteristics in the vicinity of stores and whether store entrances or

window access are blocked by deliveries. The software optimizes outbound delivery times and driving distances, but the Carrier G private fleet does not do backhauls. “Empty” trailers contain considerable packing material, further reducing the practicality of backhauls.

Carrier G’s division fleets are partially maintained by its own employees and partially by its truck leasing firm. Both are aided by commercial PM software. Carrier G’s trucks are equipped with onboard computers that capture and record rapid decelerations and other indicators of driver risk. Rapid decelerations (e.g., a 7-mph drop in 1 s or less) usually indicate driver tailgating or other at-risk behavior. Because traffic density and other driving conditions vary so much across the country, different regional divisions may have tenfold differences in average frequencies of rapid decelerations. A goal is established for each distribution center, and individual drivers are evaluated in relation to other drivers in their division. Across the entire fleet, a typical goal for drivers would be a rate of one event per 900 miles. Trucks are also equipped with electronic logs, which permit rapid identification of violations and follow-up inquiries. Sometimes violations are “technical” rather than substantial; for example, a driver caught in a traffic jam at the end of a trip may have to terminate his or her trip as soon as possible, but still go over on driving time. Such minor violations do not result in enforcement consequences, because they are infrequent and explainable.

Carrier G’s trucks are both speed limited and speed monitored. Trucks are limited to 63 mph when under power. Because trucks going downhill can accelerate to higher rolling speeds, they are monitored for any speeds greater than 68 mph. These measures control speeds and also improve fuel economy. Individual driver fuel economy also is monitored. These combined measures have allowed Carrier G to improve its fuel economy by more than 1 mpg.

Carrier G has analyzed its crashes in terms of location, vehicle movements, and other risk factors. Few of its crashes occur on Interstates or other freeways. Most actually occur at store locations, and many of these involve truck backing maneuvers. Many also occur within closed distribution center yards. Carrier G’s analyses of yard crashes has led to changes in yard design (e.g., parking lines, other markers, and signs) resulting in a 44% reduction in these crashes.

On the survey form and in the interview, the SM emphasized the many roadway factors affecting crash risk. These include divided versus undivided roadways, traffic, work zones, loading dock and yard design, and, of course, traffic density. With regard to work zones, it was pointed out that some highway work projects appear to result in lane closures of unnecessarily long durations. Such extended closures elevate crash risks because of their constricted driving space.

Five Carrier G Innovative Operational Practices

- Software for PM scheduling and records
- Routes and deliveries optimized in relation to road, traffic, and delivery location factors
- Onboard computers with monitoring of rapid decelerations with analysis of regional rates
- Truck speed-limiting with monitoring of top speeds and fuel usage
- Analysis of crash factors and resulting yard redesigns

CASE STUDY H: LARGE UTILITY PRIVATE FLEET

Carrier H is a large utility with a private fleet of trucks. These trucks deliver equipment items, both very large and small, to company locations. Most tractors are equipped with an onboard hydraulic “Knuckle Boom” crane, which is used to unload equipment from the trailer and to load used equipment for return trips. Most backhauls are loaded with equipment needing repair or to be scrapped. The interviewee has decades of experience with the company, and functions as a senior safety consultant and advisor with company-wide, national responsibilities.

Carrier H has very stable and predictable delivery operations. Its distribution center and terminal locations are established and rarely change. Its drivers and trucks deliver the same cargo items to multiple terminals, which are similar in size and operations. Drivers know their routes and the vagaries of traffic patterns along the way. Almost all daily trips begin and end within 12 hours at the equipment distribution center. Employee drivers work a 4-day week. Thus, many issues confronting other fleets are not concerns to Carrier H. These include empty backhauls, loading and unloading delays, HOS compliance challenges, route optimization, and navigation. The regularity of delivery routes, locations, and operations contributes greatly to driving safety. Most crashes involve trucks’ close interactions with other traffic, as in a “pinch” scenario when light vehicles cut in front of trucks.

Carrier H has its own maintenance facilities but also out-sources maintenance. It uses commercial maintenance management software to manage PM schedules, parts inventory, fuel and tire usage, and other maintenance schedules and records.

Carrier H emphasizes trip planning and preparation. The supervisor of the prior shift prepares a daily “run sheet” for each driver that specifies delivery points and includes paperwork for each delivery. Because drivers are familiar with their routes, they are granted the flexibility to modify them when needed, based on traffic conditions or other exigencies. Supervisors closely monitor both pre- and post-trip vehicle inspections, which include the truck, trailer, and the onboard

Five Carrier H Innovative Operational Practices

- Commercial software for PM scheduling and records
- Trucks equipped with E-Z Pass transponders; drivers use most efficient roads
- Supervisor prepares daily “run sheet” for drivers.
- Daily management monitoring of pre- and post-trip vehicle inspections
- Vehicles equipped with mobile tracking and communications

“Knuckle Boom.” The company is experimenting with an Electronic Vehicle Inspection Report system from Zonar. The system uses radio-frequency identification tags attached to key vehicle inspection points to ensure full compliance with inspection requirements and recording of inspection steps. The SM emphasizes, however, that it is people and management that ensure safety, not electronic aids.

Vehicles are equipped with Qualcomm mobile tracking and communications units. Supervisors do not monitor them continuously, however, because most daily operations are routine. Vehicles are equipped with onboard computers capable of recording driving indicators such as engine speed, idling, hard braking, and overspeeding. The company has purchased the software needed to collect and analyze these vehicle and driving data, and is beginning to implement onboard monitoring.

Often crashes and safety problems that appear to be the result of driver error are actually traceable to “system” deficiencies. The SM cited the example of a crash in which a company truck ripped down a terminal gate. The crash was at first attributed to driver carelessness, but investigation revealed that the electronic gate opening device did not allow sufficient time for the driver to activate it from outside the vehicle, return to the vehicle, and then drive through. Many crashes and employee injuries are the result of problems with loading dock and yard physical layout. They can also be related to terminal supervisors’ and employees’ failure to maintain a clean and orderly workspace. Terminal managers are evaluated and compared based on detailed and consistent record-keeping on accidents and injuries. Most often, an efficient terminal is a safe one, although there is a caveat. Some terminal managers push productivity too hard at the expense of safety.

CASE STUDY I: MEDIUM-SIZED PRIVATE AND FOR-HIRE FOOD AND GENERAL CARGO CARRIER

Carrier I is a medium-sized, short- and medium-distance transporter and logistics service provider serving the Mid-Atlantic, Northeast, and Southeast United States. The company had spe-

cialized in temperature-controlled food shipments, but now also hauls other types of cargo, including live animals. It functions largely as a private carrier because its primary operations are under a long-term dedicated contract with a food producer and shipper. It is also licensed as a for-hire carrier with truckload and scheduled LTL operations. The interviewee’s title is general manager, with duties encompassing driver hiring, training, supervision, equipment, and operations.

Carrier I has its own truck maintenance facility and manages PM using TMT Fleet Maintenance software, commercially available from TMW Systems. This software is used to manage PM schedules, parts inventory, fuel and tire usage, and other maintenance schedules and records. Equipment asset and maintenance activity data are entered once and then integrated by the software into various user-formatted reports as an aid to equipment management and budgeting.

Carrier I strives to minimize deadheads (empty backhauls) using brokers, load boards, and established contracts. It books backhauls for 95% of its longer-distance trips. Carrier I charges detention fees to receivers for unloading times greater than 3 hours, though the SM believed that such fees did not result in significant safety benefits; they “add complexity” to the business process without solving the problem of excessive delays. Drivers are reimbursed for tolls, and generally encouraged to use freeways. Dispatchers are usually aware of drivers’ trip experience, and work with drivers to make sure they have maps and directions for unfamiliar trips. Drivers can buy their own GPS navigation systems. More drivers use general-purpose systems than truck-specific navigation systems because the former are considerably less expensive (roughly \$150 versus roughly \$500).

Carrier I’s trucks are equipped with onboard communications systems, and some vehicle engines have monitoring capabilities for fuel usage and idling time. Carrier I is currently in “vendor evaluation” to add onboard computers to its entire fleet. This will uniformly equip vehicles with communications, electronic logs, engine monitoring, and driver performance monitoring (e.g., speeds, rapid decelerations). The SM believed that electronic logs would improve compliance, reduce driver fatigue, and improve the safety oversight of drivers. Efficient and successful companies were believed to be safer companies, in part because they had the resources to invest in better safety equipment and processes. Efficiencies result in more company profits to invest in safety and in more available time to focus on safety.

Currently the company pays most local-delivery drivers by the hour, but pays longer-haul drivers by the mile. The SM raised the idea that vehicle onboard monitoring equipment might make it possible to shift long-haul drivers partially from pay-by-the-mile to hourly pay, or to a system combining the two pay methods. That is because onboard monitors could be used by management to ensure that drivers were

**Five Carrier I
Innovative Operational Practices**

- Commercial software for PM scheduling and records
- Use of multiple methods to reduce deadheads to 5% of return trips
- Maps and route directions provided to drivers for trips
- Mobile communications
- Moving to electronic logs and multifunction vehicle onboard monitoring

**Five Carrier J
Innovative Operational Practices**

- Software for PM scheduling and records
- File of optimal routes for almost all trips
- Provides state daily traffic alerts to drivers
- EOBRs assist trip planning as well as HOS compliance.
- OBSM monitors fuel use and driving patterns. Prints trip “Report Card”

indeed using their time productively, one of the concerns motivating carriers to pay long-haul drivers only by the mile.

CASE STUDY J: SMALL CHARTER BUS SERVICE

Carrier J is a small, family-owned charter bus service located in New York state. Most of its trips are to New York City and other major attractions in the region. Its SM, interviewed for this case study, has 20 years’ experience in the position and 15 years’ prior experience as a driver. The SM regarded driver enduring traits and roadway and traffic characteristics to be the biggest crash risk factors. These choices show insight into two strong sources of risk variation, as indicated by naturalistic driving studies. Chapter two of this report reviewed the evidence that different highway characteristics such as road type (e.g., undivided roads versus divided highways), construction zones, and traffic density can be associated with marked differences in incident risk.

Most of Carrier J’s trips are to a number of Northeast cities, tourist attractions, and recreational areas. Because the company serves a limited number of destinations, it can prescribe a route for almost every trip. The SM regards this as a significant safety advantage because the prescribed routing can maximize travel on Interstates and on less congested roads. This also means that drivers are almost always familiar with their routes. When drivers are familiar with their routes, they can plan stops, turns, lane changes, and other maneuvers in advance. They anticipate potential trouble spots and may learn alternate routes to take when there are unforeseen backups. Drivers have access to a computer at the home office with a catalog of routes for almost all charter destinations. They can also see daily traffic alerts from New York and other state DOTs in their travel area.

Carrier J has equipped its motor coaches with a multifunction electronic monitoring system provided by a major vendor. The system provides OBSM as well as EOBR. The OBSM system records and reports “overspeed” time (i.e., above a specified top speed), highest observed speed, hard braking incidence, fuel use, and other indicators of safe or unsafe driving. It calculates a “Driver Report Card” for each trip. Driver acceptance of the monitoring is surprisingly good;

indeed, they “make it a competition” to see who can earn the best scores. EOBRs are more accurate than paper logs and increase safety by improving HOS compliance. EOBR benefits are not limited to fatigue reduction, however. They make operational planning and safety management more efficient, and enable quick identification of problems. The system’s GPS real-time mapping feature can provide a location-by-time “cookie trail” for any trip, vehicle, or driver.

The Carrier J SM believed that efficient carriers were generally safer carriers. One exception cited, however, was from previous experience with pickup and delivery operations. Too tight monitoring of delivery times forces drivers to rush, leading to potential errors, mishaps, and even crashes.

CASE STUDY K: SMALL CHARTER AND SCHEDULED BUS SERVICE

Carrier K operates about 50 motor coaches in the Midwest. These buses carry 29 to 56 passengers, and originate from three company terminals. Services include charters, tours, shuttles, airport transfers, casino runs, and daily scheduled routes. The company carries more than 750,000 passengers annually. The company’s SM and interviewee for this summary holds the dual title of director of safety and training.

In the study survey, the SM rated maximizing day driving, avoiding adverse weather, and assigning familiar routes to drivers as the most safety-effective operational practices of those presented. The company had conducted no statistical studies of crash rate by hour-of-day, but regarded overnight driving, particularly between 2:00 a.m. and 6:00 a.m., as the most dangerous. Long trips ending in these early morning hours were especially to be avoided. Evenings between 6:00 p.m. and midnight, on the other hand, were regarded as among the safer time periods for driving. Company buses on scheduled routes have lower crash rates than those on charters, reflecting, in the SM’s opinion, drivers’ greater familiarity with routes and traffic patterns.

Carrier K performs PM conscientiously, using commercially purchased PM scheduling and tracking software. General, non-commercial-vehicle GPS navigation aids are provided to drivers. Although the company works from three

terminals, dispatching is from a single location, using a computerized system. Vehicles are OBSM-equipped to record vehicle speeds, fuel use, and idling times. *SmarTire*[®] provides automated pressure monitoring and inflation. These applications are motivated primarily by efficiency and cost-reduction, but their safety benefits are recognized. The SM believes that efficient carriers are usually safer carriers, because of their established and continuous procedures and expectations. These systems allow for quicker correction of deviations and problems. A concern, however, is that proliferation of in-vehicle safety- and efficiency-related devices could lead to greater driver distraction and information overload.

**Five Carrier K
Innovative Operational Practices**

- Commercial software for PM scheduling and records
- Avoids long trips ending in the early morning
- Computer-aided dispatching from single location
- OBSM records speeds, fuel use, and idling times.
- Automatic tire pressure monitoring and inflation

CONCLUSIONS AND FURTHER RESEARCH

This report has gathered research, vendor, survey, and interview data on commercial motor vehicle (CMV) transport *risk avoidance strategies*; that is, ways in which motor carriers can conduct their operations and deploy their assets to minimize crash risk. In this context, risk avoidance can be distinguished, at least conceptually, from conventional *risk reduction*. Risk reduction, constituting the majority of carrier safety efforts, improves the safety performance of individual “assets”—that is, drivers and vehicles. Risk reduction usually involves making company investments in proven interventions, such as improved driver selection, training, management oversight, or vehicle safety equipment. These actions are often evaluated based on their benefits per unit of cost.

As defined here, risk avoidance strategies may also be conceptualized as carrier efficiencies with potential benefits to safety. This is an easier and more inclusive way to define these approaches; hence the report title *Safety Effects of Carrier Efficiencies*. The following specific carrier practices and operational issues were discussed:

- Employing preventive maintenance (PM);
- Reducing empty (“deadhead”) trips;
- Minimizing loading, unloading, and related delays;
- Optimizing routing and navigation:
 - Providing navigational and routing aids;
 - Assigning familiar routes to drivers;
- Selecting road type: divided versus undivided roads;
- Avoiding work zones;
- Avoiding traffic;
- Emphasizing efficient scheduling: optimal times for safe travel;
- Avoiding adverse weather;
- Using higher-productivity vehicles (HPVs);
- Using onboard computers and mobile communications;
- Maximizing team driving;
- Using electronic onboard recorders (EOBRs);
- Optimizing fuel economy and safety:
 - Using speed limiters;
 - Monitoring driver fuel economy; and
- Monitoring vehicle condition.

These practices have in common that they are potentially time- or cost-saving practices with concurrent safety effects, mostly benefits, of interest. Secondly, they are *pre-trip* or *pre-crash threat* interventions. They are deployment, operational, or driving-route selection practices that potentially affect expo-

sure to crash threats rather than improve direct responses to crash threats. Many of the individual strategies may appear to have the potential to reduce carrier crash rates by just a few percentage points. Concurrently adopting multiple strategies, however, could result in significant carrier crash reductions. Considering these strategies is an attempt to broaden the scope of commercial vehicle crash analysis and prevention. This expanded perspective seeks to expand motor carrier safety management to include safety-proactive operational planning.

SAFETY-RELEVANT CARRIER EFFICIENCIES

Chapter two of this report presented the 15 categories of carrier efficiencies, along with a general conceptualization of how these strategies work in crash reduction. The *Haddon Matrix* provides a general conceptual structure for identifying factors that influence crashes and outcomes. It divides the crash scenario in terms of time frame (i.e., pre-crash, crash, and post-crash) and in terms of the primary “actors” affecting the event (human, vehicle, and roadway and environment). For motor carrier safety, expansion of the Haddon Matrix is warranted to allow for both a broader time frame and more prominent “actors.” Expansion of the pre-crash time frame into pre-trip, pre-threat, and pre-crash impact facilitates consideration of carrier efficiencies and other strategies that avoid risk before that risk is confronted directly.

Vehicle mechanical deficiencies are not among the top proximal causes of commercial vehicle crashes, but they are strongly *associated* with crash risk. Vehicle PM is reliably practiced and strongly supported by safety-conscious carriers and managers. Of practices presented in the current safety-manager survey, PM was both the most frequently used and the most strongly supported for safety. Most respondents also used maintenance management software and supported its use. These products provide many specific useful applications.

One of the simplest ways to improve safety through improved efficiency is to reduce empty backhaul trips (“dead-heads”). Reducing empty miles is primarily motivated by its financial benefits, but there is also a proportional safety benefit. Every empty mile avoided reduces crash risk without reducing productivity and revenues. For-hire carrier empty miles have averaged about 20% of their total travel in recent years, but many efficient carriers are using web-based load boards and other means to reduce their empty miles to as low

as 10%. Reducing empty miles does not necessarily reduce carrier crash rate per vehicle-miles traveled, but does reduce crash rate per unit of productivity, ultimately a more compelling metric.

As with empty miles, lost time owing to truck loading and unloading delays is a form of asset underutilization. Such time delays are more insidious, however, as they are more likely to affect driving performance. Drivers are generally unable to use waiting times for sleep or other restorative rest. Hours spent waiting but awake contribute to driver fatigue later, on the road. Schedule pressure or frustration may cause drivers to speed or otherwise hasten their work unwisely. Whereas system-wide technological changes may reduce the problem, the principal carrier countermeasure is to charge detention fees to customers for excessive delays (usually those more than 2 hours). Charging detention fees appears to help, but does not eliminate the problem.

Smoother routing and navigation improve the efficiency of CMV operations. Each time a truck accrues unnecessary miles (or unnecessarily risks miles) because of poor routing, its equipment is not being utilized efficiently and risk has not been minimized. Drivers also perform more safely when they know or can easily follow their routes. A distinction can be made between *routing* and *navigation* in CMV operations. *Routing optimization* generally refers to improvements in the efficiency of the overall delivery operation. *Navigation aids* are devices to help drivers make a particular point-A-to-point-B trip. Most responding carriers used or encourage use of global positioning system navigation systems by drivers. The use of truck-specific routing and navigation systems was recommended by many. These systems help truck drivers avoid low underpasses and other large-truck hazards and restrictions. These systems offer many more features in support of trip management. A simple, non-technological way to improve both efficiency and safety is to assign drivers familiar routes when possible.

The safety advantages of divided over undivided highways are well known to highway engineers and safety researchers. Depending on the metric and study, undivided roads have two to five times the risk of divided roads. Survey results indicate that responding safety managers also appreciated the safety of Interstates and other divided, limited-access roads over undivided roads. Most responding companies encouraged the use of toll roads by providing drivers with toll transponders (e.g., EZ Pass) or fully reimbursing tolls. This prevents driver diversion from toll roads onto smaller, higher-risk roads.

Highway work zones are very-high-risk areas for all vehicles, especially large trucks. Crash threats in work zones include constricted lanes, narrow or absent shoulders, makeshift signs, and traffic backups where light vehicles may dart in front of trucks to move up in the queue. Large-truck naturalistic driving research, whereby the locations of incidents can be compared with randomly selected

exposure points, suggests an almost tenfold increase in risk in work zones. Thirteen percent of all truck crash involvements in the Large-Truck Crash Causation Study (LTCC) occurred in work zones, a percentage far above mileage exposure in work zones. Avoiding work zones was recognized by survey respondents as an important safety strategy.

In recent decades, all across the United States, traffic delay has increased in urban areas, whether relatively small, medium-sized, or large. The recession of recent years has caused only a slight and temporary dip in urban traffic. In larger urban areas, free traffic flow occurs reliably only between 9:00 p.m. and 5:00 a.m. Predictable and significant congestion lasts for about 3 hours during both morning and evening peak hours. Increases in traffic density and travel times generate disproportionate increases in interactions among vehicles and associated crash risk. Large-truck naturalistic driving data suggest that driving in heavy traffic involves six times more risk than driving in lighter traffic. About 45% of combination-unit truck (CT) driving and 57% of single-unit truck (ST) driving takes place in urban areas, and trucks in the LTCCS were more likely to be at-fault in multivehicle crashes in urban than in rural areas. Both safety-manager and other-expert survey respondents recognized the safety value of avoiding urban traffic. A new Freight Performance Measures service available from the American Transportation Research Institute and FHWA provides extensive and detailed travel time data to allow carriers to adjust their operations toward faster Interstate highway freight lanes and faster times for travel. Routing and navigation software vendors are making progress in incorporating traffic avoidance into their programs.

Given the strong effects of traffic density on crash risk, one would think that off-peak driving, particularly night driving when traffic densities are lowest, would always be safest. Opposing this idea is the concept that driver fatigue is greatest in overnight hours, particularly in early morning, between 3:00 a.m. and 6:00 a.m. The overall time-of-day distribution of large truck crashes, available exposure data, and naturalistic driving studies suggest that day driving is more risky than night driving because of the presence of other vehicles. However, overnight driving clearly is more risky from the standpoint of driver alertness and asleep-at-the-wheel risk. In this project's surveys, both groups of respondents generally considered day driving to be safer than night driving. One conclusion consistent with all research reviewed is that the evening hours between 6:00 p.m. and 2:00 a.m. are probably among the lowest-risk travel times for large trucks. Given the disparity of research findings and opinions regarding other times of the day, however, conclusive research on the issue is needed. Reliable guidance on the question likely could reduce significantly the risk exposures of companies with time-of-day flexibility in their operations.

Adverse weather is an obvious source of risk in driving and, when extreme, can be a direct crash cause. In the LTCCS, 14%

of truck crash involvements had weather as an associated factor, but less than 1% of truck at-fault crashes were assigned a weather-related Critical Reason (proximal cause). In other words, bad weather contributes to many truck crashes, but is the proximal cause of only a few. In this project's surveys, the factor "weather and roadway surface conditions" was considered less important than enduring driver traits, temporary driver states, and roadway characteristics and traffic conditions (e.g., road type). Only the factor "vehicle characteristics" was rated as less important. These survey results are consistent with research findings.

The question of truck size and crash risk is much like the question of time-of-day and crash risk. Differences of opinion abound, but it is difficult to draw reliable conclusions based on available research. Larger trucks might be safer if using them results in fewer trucks on the road and, therefore, less exposure to risk. Smaller trucks might be safer if they are individually less likely to figure in crashes or if their crashes are less severe because of their smaller size. In a current analysis based on several data sources, CTs and STs were found to have about the same total crash costs per mile traveled. This replicates a finding of a previous study by Wang in 1999. However, one cannot base operational decisions on this finding, because the uses and road type exposures of CTs and STs are different. Two major Canadian studies suggest that HPVs can be operated with equal or lower crash rates than one-trailer CTs. However, average crash severity of HPVs may be much higher than that of CTs, which perhaps cancels out their potential safety benefits. Project survey findings somewhat favor the use of larger trucks, but there are many contrary views as well.

Commercial vehicle onboard computers and mobile communications (also known as *telematics*) cover a wide range of potential applications for operations and safety. Many of these applications are beyond the scope of this report. The report discussion focused on those specific telematic applications mentioned by motor carriers in project surveys and interviews that relate to both operational efficiency and safety. These were discussed primarily with regard to safety benefits, though some concerns were expressed about safety losses owing to driver distraction. Onboard computer and communications suites are becoming complex and comprehensive fleet monitoring and management tools. Systems allow central, real-time viewing of a vehicle's map location, moving speed, engine speed, battery and fuel status, and trip history. Vehicle component (e.g., brake, tire) condition monitoring is also available. Systems can be programmed to flag any trouble indicator, whether it relates to vehicle functioning or driver behavior. A safety concern arises, though, with regard to driver use of onboard systems during driving. Some carriers program their onboard systems to withhold visual displays from drivers when vehicles are moving.

Four topics were added to the study based on comments by carrier safety managers on project surveys and interviews

for the case studies. The four topics are team driving, EOBRs, fuel economy and safety, and vehicle condition monitoring. Brief discussions of each were provided. Team driving is an efficiency practice because a long-haul, team-driven truck can legally be moving almost continuously during an extended trip. Team driving has several important safety advantages. Most notably, the presence of another person in a vehicle reduces unsafe driver practices, including the tendency to continue to drive even when excessively drowsy. The major disadvantage of team driving is that sleep in a moving vehicle is usually lighter and less restorative. Still, a naturalistic driving comparison of team and solo driving found the incident rate among team drivers to be less than one-half that of solo drivers.

This report did not address regulatory or hours-of-service (HOS) compliance issues relating to EOBRs, but did touch on their safety management applications. EOBRs are used voluntarily by a growing number of CMV fleets, and they were cited as aids to both efficiency and safety by several interviewees. By automating driver log-keeping, EOBRs save drivers' time, streamline records and compliance management, and provide a means for safety oversight of drivers through quick identification of noncompliant drivers. EOBRs facilitate load assignments in larger fleets by identifying drivers with sufficient time available for the loads. Shackelford and Murray (2006) found other EOBR benefits to include improved fuel consumption monitoring and fuel tax compliance, quicker tabulation of driver mileage and loads, easier tracking of vehicle and engine wear, and better communications and dispatching.

The link between fuel economy and safety was noted by several interviewees, and is well established by research. Improved fuel economy is achieved in large part by changes in vehicle speed and driving style. These changes in turn produce safety benefits such as reduced driver stress, crash likelihood, and crash severity. Two primary approaches to improving fuel economy with concomitant safety benefits are speed-limiting vehicles and monitoring individual driver fuel consumption. *CTBSSP Synthesis Report 16* examined the safety impact of large-truck speed limiters. In its project survey, most carrier respondents indicated that speed limiters were either "successful" or "very successful" in reducing crashes. Almost all of them believed that speed limiters had no negative effects on their company's safety and productivity. A more direct method for improving fuel economy is to monitor fuel use of individual drivers and trips. A capability for onboard fuel consumption monitoring is commonplace in today's trucks. Almost all of the project case study companies monitor individual driver fuel use and component behaviors, such as hard braking and speeding. For example, Carrier J, a small charter bus company, uses onboard safety monitoring of driving behaviors and fuel use. The system generates a "Driver Report Card" for each trip. Driver acceptance of the monitoring has been good; they "make it a competition" to see who can earn the best scores.

Automatic monitoring of vehicle condition was cited by several case study interviewees as a growing application with both safety and efficiency benefits. Onboard monitoring of vehicle condition complements and extends the high-quality vehicle maintenance programs of many top fleets. Tire pressure monitoring exemplifies truck vehicle condition monitoring. In the LTCCS, 1.1% of at-fault truck crashes were caused primarily by tire failure, which is usually the result of underinflated tires. A 2003 study of truck tire inflation by Kreeb et al. found that fleet maintenance of tires was often poor, resulting in high rates of tire underinflation. Improper inflation raised tire-related costs by \$600 to \$800 annually per tractor-trailer combination. About 5% of fleets currently use onboard tire pressure monitoring systems. A recent fleet test of tire pressure monitoring systems found their use to be associated with slower tire wear and 1.8% better fuel economy.

What about the *general* relationship between efficiency and safety? Do the various efficiency practices add to greater safety? Do carrier practices that foster efficient operations also foster safe operations? The project did not *measure* either the efficiency or safety of any fleet, so it cannot provide definitive evidence. A survey question asked respondents about the general relationship. Strong majorities of both categories of respondents believed that, “Highly efficient carriers tend also to be *more safe* than other carriers.” Other studies suggest a positive relationship between systematic, high-performance company management and worker safety. This is especially true if company efficiency and growth can be achieved without putting excessive productivity and delivery pressure on drivers. Survey comments reinforced the notion of a positive relationship, with the same caveat about avoidance of excessive stress on drivers.

By and large, the safety-manager and other-expert survey responses paralleled the findings of the literature review on various report topics. A top-level exception, however, was seen in the results of the opening survey questions on general factors affecting crash risk. In Questions 1 and 2 (for both safety managers and other experts), respondents were asked to select from the following the two factors with the greatest general effect on crash risk, and the one factor with the least effect:

- (a) Enduring driver traits;
- (b) Temporary driver states;
- (c) Vehicle characteristics and mechanical conditions;
- (d) Roadway characteristics and traffic conditions; and
- (e) Weather and roadway surface conditions.

For safety managers, the vehicle-related choice (c) received the fewest “most” votes, whereas choice (d), “roadway characteristics and traffic conditions,” received the greatest number of “least” votes. Thus, both (c) and (d) could be regarded as “losers.” Ironically, perhaps, choice (d) has the greatest relevance to the current study, because many operational transport efficiencies related to roadway and routing choices.

Empirical data (e.g., those related to divided and undivided highways and traffic density) demonstrate that the category (d) does affect crash risk strongly. For the other expert respondents, choice (d) was at the middle of the five factors with regard to its effects on crash risk.

Most of the specific driving situations and operational practices presented to both respondent groups received positive ratings for safety. “Maximizing travel on low-speed roads,” presented as the opposite of “maximizing travel on Interstates and other freeways,” received the highest negative ratings. Day driving was favored over night driving by both respondent groups, but with disagreement by some respondents. The two contrasting items on truck size generated the widest variation of responses and disagreement. Although using “fewer, larger trucks” received slightly higher mean ratings by both groups, there was no consensus. PM was the most widely practiced and rated carrier risk-avoidance practice.

REPORTED EFFECTIVE CARRIER PRACTICES

The project evidence and product review (chapter two), surveys (chapter three), and case studies (chapter four), as well as past reviews, indicate the following as common and beneficial carrier practices for consideration:

- Operational planning and pre-trip actions (i.e., many of the strategies discussed herein) to reduce crash risk systematically;
- Pre-trip planning for individual trips, to include routes and schedules, including planned rest stops;
- PM schedules and records for each vehicle, aided by maintenance management software;
- Aggressively reducing empty backhaul trips for financial benefits and to reduce unnecessary risk exposure;
- Reducing loading and unloading delays by working with shippers and receivers and by changes in carrier operations;
- Optimizing routing for individual vehicles and whole operations. Expedited travel through improved routing generally translates into safety gains as well;
- Providing truck-specific navigational aids to drivers;
- Assigning familiar routes to drivers when possible;
- Routing vehicles through divided, limited-access roads (e.g., Interstates) when feasible, even at the expense of extra miles;
- Avoiding highway work zones when feasible;
- Avoiding urban areas when feasible, in particular during morning and evening peak hours;
- Avoiding adverse weather and slippery road surfaces when feasible;
- Using onboard computers and mobile communications for driver monitoring and to support operational efficiencies, but with measures to ensure that drivers are not distracted while driving;
- Using speed limiters;

- Monitoring individual driver fuel economy and providing feedback to drivers;
- Using onboard tire pressure monitoring systems and other vehicle condition monitors as they become more available in vehicles; and
- Generally, developing carrier efficiencies and disciplined operational practices that will support safety but will not create pressures on drivers or others to push delivery schedules or other activities to unsafe speeds.

In addition to the established practices, this project has reported research, survey, and interview findings suggesting the potential value of the following for some carriers:

- Charging detention fees to customers for excessive loading and unloading delays;
- When operationally feasible and within HOS constraints, scheduling trips to include the evening hours between 6:00 p.m. and 2:00 a.m. if daytime traffic and associated inefficiencies and risks are concerns;
- Using team drivers when feasible;
- Using EOBRs for a variety of efficiency and safety management benefits;
- Equipping large trucks with automated transmissions to lessen driver workload and increase attention to driving;
- Developing better and more detailed exposure statistics to use as denominators in safety evaluations. These might include vehicle-miles traveled, hours of driving (from HOS logs), trips, ton-miles, and revenue. Disaggregation of exposure by company depot, vehicle configuration, location and region, time-of-day, day-of-week, and other classifications would permit better safety assessments and shifting of operations toward lower risk conditions; and
- Joining or forming a consortium of similar carriers who meet regularly to share information about improving safety and reducing losses. In such consortia, carriers can share techniques and procedures for improved operational efficiency and safety.

RESEARCH AND DEVELOPMENT NEEDS

In 2008, 9,006,738 large trucks traveled 227.5 billion miles in the United States. The average per-vehicle annual mileage for CTs was 64,764 miles. In addition, 843,308 buses traveled 7.1 billion miles. Given all of these miles traveled and the associated exposure to risk, there would appear to be abundant opportunities for quantitative analyses of commercial vehicle travel patterns and other operations to identify efficiencies with safety benefits. Much of this research would elaborate on the findings reviewed previously and provide more compelling arguments for various carrier or industry operational changes. Other research would help to resolve specific unanswered questions about carrier operations and safety.

Most transportation safety statistics are more meaningful and heuristic if they are derived in part from some *exposure*

measure. Carrier exposure data include vehicle mileage, hours of driving, times of driving (i.e., times-of-day and days-of-week), geographic locations, freight lanes (corridors), types of runs, vehicle types, and many other “denominator” metrics. Much of crash-risk analysis consists of simple calculations of rates based on event (crash, incident, violation) numerators and exposure denominators. For example, a common rate calculated by carriers is crashes (e.g., police- or DOT-reported) per mile. Calculation of *relative* crash risks for different categories of exposure is a more powerful risk analysis tool because it identifies higher- and lower-risk exposures within a company’s operations. Relative crash risk is determined by the following formula:

$$\text{Relative Crash Risk} = \frac{(\text{Factor \% in Crashes})}{(\text{Factor \% in Normal Driving})}$$

A simple example would be a carrier’s analysis of its crashes on different freight lanes or corridors (e.g., I-40, I-70, and I-80). If the carrier collected and classified both its crash and mileage data by freight lane, then it could determine relative crash risks on those lanes. For large carriers, such analyses might provide statistically reliable guidance for reducing risk exposure. Some carriers interviewed for the case studies conduct extensive risk analyses, but the practice appears to be limited to large and progressive carriers. Carriers might benefit from more guidance and tools for collecting better internal exposure data and using that data in risk analysis.

In an Australian study, Wright et al. (2005) identified the same need for quantitative safety and productivity analyses within fleets. The authors conducted in-depth surveys and interviews with managers at 12 motor carriers. All companies provided qualitative assessments of their safety programs and associated costs and benefits. Only a few companies, however, were able to provide even a limited amount of quantitative data, suggesting that rigorous safety program evaluation was lacking among Australian motor carriers.

Two operational issues presented on project surveys generated the widest variations in opinion. Research gaps were also seen in these areas. The first was day versus night driving. There would be many operational safety applications from better data and knowledge on CMV crash risks as a function of time of day. No one has determined whether night driving is generally more or less dangerous for CMVs than daytime driving. Yet, the answer is relevant to millions of truck dispatch decisions made annually. Many assume that night driving is less safe than day driving because of the greatly elevated driver fatigue risk associated with the early morning circadian valley, and because light-vehicle serious crash rates spike during the overnight hours owing to alcohol impairment and reckless driving. Yet, truck crash rates vary strongly with traffic density, and traffic densities are lowest at night. Large-truck naturalistic driving data suggest that night driving is less dangerous because there are fewer traffic interactions. The time-of-day distributions of truck crashes in the LTCCS and national crash databases suggest the same

(as reviewed in the section “Efficient Scheduling” in chapter two). However, both the safety-manager and other-expert surveys found majorities of respondents believing day driving to be safer. Systematic study could answer this question. Two potential approaches are time-of-day studies of crashes per unit of exposure for limited-access roadways (e.g., toll roads) and large-carrier-based studies in which both crashes and exposure are closely tracked company wide. Both types of studies could be enhanced by the use of additional numerators (e.g., tabulations of total crash harm in addition to crash counts) and control for roadway type.

The second issue generating extremes of opinion was that of truck size and safety. The question whether HPVs are to be used more widely on the U.S. road system is both controversial and difficult to answer objectively. Although the issue has been discussed here in the context of operational efficiency and safety, HPVs are also problematic with regard to vehicle stability, pavement wear, and bridge weight capacity. Nevertheless, studies could compare freight movement productivity (e.g., freight ton-miles and comparable freight volume metrics) with crash harm for different truck configurations, including STs, CTs, and HPVs. Different truck configurations may also be assessed with regard to fuel consumption and emissions per unit of freight movement.

This project has presented evidence linking traffic congestion to crash risk, and also evidence of the safety benefits of transport route optimization and navigation aids. Navigation aid vendors are beginning to equip systems with real-time updates based on ambient traffic conditions. Real-time routing updating is a relatively new application that will see continued development and more widespread use in the coming years. Systems providing such real-time updates and adjustments primarily use global position system-equipped cell phone transmissions as a source of data on traffic movements. The principal challenge is in analyzing such massive data in real time to produce reliable adjustments in routing guidance.

The Intelligent Transportation Society of America has published a white paper entitled, “Smart Mobility for a 21st Century America: Strategies for Maximizing Technology to Minimize Congestion, Reduce Emissions, and Increase Efficiency.” The publication relates to motor vehicle and other modal transportation in general, rather than specifically to CMV transport. Nonetheless, its five broad innovation strategies apply also to CMV transport and to topics addressed in this report. The innovations include:

- Making transportation systems more efficient;
- Providing more travel options;
- Providing travelers with better, more accurate, and more connected information;
- Making pricing and payments more convenient and efficient; and
- Reducing trips and traffic.

Many of the same evaluation criteria for in-vehicle safety technologies (e.g., collision warning systems) also apply to products and services intended to make operations more efficient. These decision factors are critical for making, using, and buying technologies in the CMV industry. They include:

- Return on Investment for the Purchaser: Sustains commercial success of technologies purchased and used by carriers;
- Initial Cost: Affects early deployment, because a high initial-purchase cost makes it difficult for a carrier to raise the needed capital to buy technologies;
- Demonstrated Effectiveness to Improve Safety, Security, and Efficiency of Operations: Represents the major benefits that offset the costs of technologies;
- System Reliability and Maintainability: Provides the results and usability of technologies for carriers and manufacturers (original equipment manufacturers and vendors);
- Driver Acceptance: Ensures that drivers are receptive to technologies that are user-friendly and effective in improving safety and security;
- Market Image: Involves using state-of-the-art technologies to improve a carrier’s image by designating a company as progressive and concerned about the safety and security of their drivers and loads;
- Market Demand: Depends on awareness of the technology, along with acceptance and belief in its value, which is particularly important to manufacturers introducing a new product;
- In-Cab Technology Interface Integration: Minimizes cost, distraction, and human errors while using the technology; and
- Liability: Influences carriers, drivers, and manufacturers, particularly relating to the data stored by certain technologies and their use.

Several of the operational practices in this report were addressed under the Motor Carrier Efficiency Study (MCES). The MCES *Inefficiencies Report* pointed out that a common thread running through many inefficiencies is delay resulting in large part from parties (e.g., customers) or forces (e.g., weather and traffic) external to carriers. The inefficiencies may be mitigated, however, by improving the quality, accuracy, and timeliness of data available to transport operators. Thus, a research and development opportunity is to determine data needs, collection methods, analysis routines, and means of transmission to provide timely, operations-critical information to carriers and to drivers.

Phase II of the MCES, in planning at this writing, will pilot test technological interventions to provide carriers with operational information in areas such as the following, addressed in this report:

- Reducing time waiting to be loaded or unloaded, or to access the facilities where these activities are done;
- Reducing empty trips, particularly when interchanging loads between intermodal facilities;

- Reducing delays associated with congestion—particularly congestion associated with traffic incidents; and
- Reducing fuel consumption, likely by providing motor carriers with means to better control truck speeds.

Except in the area of preventive maintenance, this project did not specifically address carriers' use of databases, spreadsheets, and other software for safety and operational management. This would be a detailed project in itself. Nevertheless, this is an area in which management efficiency is likely to have clear safety benefits. These safety benefits may be similar to the benefits of maintenance management efficiency, except on a broader scale. Databases can enhance safety management applications such as the following (most from Safe Road Systems 2010):

- Creating custom driver scorecards;
- Tracking CSA 2010 compliance by driver;
- Managing DOT inspections;
- Monitoring crash, incident, and violation statistics;
- Scheduling drug tests;
- Tracking HOS compliance;
- Tracking OBSM data;
- Tracking route experience; and
- Monitoring driver license status and certifications.

This report, previous CTBSSP reports, and other frequently cited studies of carrier safety management have been based

primarily on successful, safer-than-average carriers. That is primarily because these carriers are active in national CMV transport organizations and conferences. They are more likely to be known to researchers and much more likely to be willing to participate in safety management studies. Studies of motor carriers with a wider range of safety performance records would strongly test safety management conclusions drawn in this and other studies based mainly on safety-conscious motor carriers and their officials. Such studies could be structured as case-control or parametric comparisons between carrier practices and their safety performance criterion measures.

Another research method applicable to validating risk-avoidance strategies is the intensive carrier case study. In 2009, Murray et al. conducted and published a 4-year occupational road safety case study of Wolseley, the world's largest heating and plumbing distributor, based in the United Kingdom and operating in 28 countries. The comprehensive case study classified dozens of Wolseley safety interventions within an expanded Haddon Matrix and chronicled their implementation and safety outcomes over a 4-year period. The company reduced its crash rate by more than 40% over the period. It also reduced employee injuries, traffic and regulatory violations, and financial losses. Although this holistic research approach does not isolate the effects of single interventions, it does "tell a complete story," which other companies may choose to emulate.

REFERENCES

- Aarts, L., *Working Group on Heavy Vehicles: Regulatory, Operational and Productivity Improvements*: Chapter 8 “Potential Changes and Their Impacts; Template for a Systematic Analysis of Potential Changes,” OECD/ITF Joint Transport Research Centre, June 19, 2008.
- American Association of State Highway and Transportation Officials (AASHTO), *Unlocking Freight: Part 2 of Operation Reboot: Restarting America’s Most Essential Operating System*, Washington, D.C. [Online]. Available: http://expandingcapacity.transportation.org/unlocking_freight [accessed July 2010].
- American Transportation Research Institute (ATRI), “Energy and Emissions Impacts of Operating Higher Productivity Vehicles Update: 2008” Research results summary [Online]. Available: http://www.atri-online.org/research/results/environmentalfactors/2008_atri_hpv_1_pager.pdf.
- American Transportation Research Institute (ATRI), “Measuring Travel Time in Freight Significant Corridors,” Research Results summary, 2010 [Online]. Available: www.atri-online.org.
- American Trucking Association (ATA), Petition for rule-making before NHTSA to amend 49 CFR Part 571: to require vehicle manufacturers to install speed limiting devices set at no more than 68 mph on new trucks with a GVWR of greater than 26,000 pounds. Petition for rule-making before FMCSA to amend 49 CFR Parts 393 and 396: to prohibit the adjustment of maximum speed on an installed speed limiting device on new trucks or truck trailers with a GVWR of greater than 26,000 pounds to a limit greater than 68 mph, Oct. 2006.
- American Trucking Association Foundation (ATAF), *Safe>Returns: A Compendium of Injury Reduction and Safety Management Practices of Award Winning Carriers*, ATAF publication No. C0938, Arlington, Va., 1999.
- Arsenault, C., “CSA 2010 and Preventive Maintenance,” *Transport Topics*, editorial, Mar. 22, 2010, p. 9.
- Belella, P., et al., *Motor Carrier Efficiency Study Phase I*, Report No. FMCSA-RRT-09-015, Federal Motor Carrier Safety Administration, Washington, D.C., Feb. 2009.
- Bennett, S., “Smart Routing to Save Fuel,” *Light and Medium Truck*, Aug. 2008, reprinted in *The Best of Transport Topics Magazines*, 4th ed., 2009, pp. 14–18.
- Bishop, R., D. C. Murray, W. McDonald, J. S. Hickman, and G. Bergoffen, *CTBSSP Synthesis 16: Safety Impacts of Speed Limiter Device Installations on Commercial Trucks and Buses*, Transportation Research Board of the National Academies, Washington, D.C., 2008.
- Blower, D. F., “Maintain Key Truck Systems for Safety,” In *Safety for the Long Haul: Large Truck Crash Risk, Causation, and Prevention*, R. R. Knipling, ATA, Arlington, Va., 2009, p. 265.
- Blower, D. F. and K. L. Campbell, *Fatalities and Injuries in Truck Crashes by Time-of-Day*, Report for FHWA Office of Motor Carriers, Contract No. DTFH61-96-C-0038, Federal Motor Carrier Safety Administration, Washington, D.C., Oct. 1998.
- Blower, D. F. and K. L. Campbell, *Methodology of the Large Truck Crash Causation Study*, Report No. FMCSA-RI-05-035, Federal Motor Carrier Safety Administration, Washington, D.C., Feb. 2005.
- Blum, M. L. and J. C. Naylor, *Industrial Psychology: Its Theoretical and Social Foundations*, Harper & Row Publishers, New York, N.Y., 1968.
- Caird, J. and T. J. Kline, “The Relationship Between Organizational and Individual Variables to On-the-Job Driving Accidents and Accident-Free Kilometers,” *Ergonomics*, Vol. 47, 2004, pp. 1598–1613.
- Clarke, R. M., R. W. Radlinski, and R. R. Knipling, *Improved Brake Systems for Commercial Motor Vehicles*, NHTSA technical report, Publication No. DOT HS 807 706, National Highway Traffic Safety Administration, Washington, D.C., Apr. 1991.
- Corsi, T. M. and R. E. Barnard, *Best Highway Safety Practices: A Survey of the Safest Motor Carriers About Safety Management Practices*, Final Report, FMCSA Contract No. DTFH61-98-X-00006, Federal Motor Carrier Safety Administration, Washington, D.C., 2003.
- Corsi, T. M., R. Barnard, and J. Gibney, *Motor Carrier Industry Profile: Linkages Between Financial and Safety Performance Among Carriers in Major Industry Segments*, FMCSA Report No. FMCSA-RI-02-009, Federal Motor Carrier Safety Administration, Washington, D.C., Oct. 2002.
- Dammen, S. J., “The Effects of Safety Practices, Technology Adoption, and Firm Characteristics on Motor Carrier Safety,” *Journal of the Transportation Research Forum*, Vol. 44, 2005, pp. 103–120.
- Delcan Corporation, *Motor Carrier Efficiency Study Final Literature Review Report*, FMCSA Contract # DTMC75-06-C-00012, Federal Motor Carrier Safety Administration, Washington, D.C., Mar. 2007a.
- Delcan Corporation, *Motor Carrier Efficiency Study Draft Inefficiencies Report*, FMCSA Contract # DTMC75-06-C-00120 Task 4, Federal Motor Carrier Safety Administration, Washington, D.C., July 2007b.
- Dewar, R. E. and P. L. Olson, *Human Factors in Traffic Safety*, Lawyers & Judges Publishing Company, Inc., Tucson, Ariz., 2002.
- Dingus, T. A., et al., *Impact of Sleeper Berth Usage on Driver Fatigue*, Final Report, NHTSA Contract No. DTFH61-96-00068, National Highway Traffic Safety Administration, Washington, D.C., 2001.
- Evans, L., *Traffic Safety*, Science Serving Society, Bloomfield Hills, Mich., 2004.
- Faulks, I. and J. Irwin, “Can Haddon’s Matrix be Extended to Better Account for Work-Related Road Use?” In *STAYS SAFE 57, Work-Related Road Safety*, I. Faulks,

- Ed., Report of the Joint Standing Committee on Road Safety, New South Wales, Sydney, Australia, 2002.
- Federal Highway Administration (FHWA), "Converting Two-Lane Highways to Four-Lane Can Reduce Crashes." *Research & Technology Transporter*, FHWA-RD-00-015, FHWA, Washington, D.C., July 2000.
- Federal Highway Administration (FHWA), "Clarus: A Clear Solution for Road Weather Information," flyer, 2007 [Online]. http://www.clarusinitiative.org/documents/Clarus_TRB_2007flyer_rev.pdf. Federal Motor Carrier Safety Administration (FMCSA), *Impact of Sleeper Berth Usage on Driver Fatigue: Final Report*, Tech Brief. No. FMCSA-MCRT-02-070, FMCSA, Washington, D.C., 2002.
- Federal Motor Carrier Safety Administration (FMCSA), *Driver Distraction in Commercial Vehicle Operations*, Tech Brief, FMCSA-RT-09-045, Sep. 2009.
- Federal Motor Carrier Safety Administration (FMCSA), Motor Carrier Safety Progress Report as of December 31, 2010 [Online]. Available: <http://www.fmcsa.dot.gov/facts-research/art-safety-progress-report.htm> [June 2011].
- Federal Motor Carrier Safety Administration (FMCSA), Analysis Division, *Large Truck Crash Facts 2008*, FMCSA-RRA-10-043, FMCSA, Washington, D.C., Mar. 2010.
- Federal Motor Carrier Safety Administration (FMCSA), Technology Division, "Commercial Motor Vehicle Safety and Security Systems Technology," [Online]. Available: <http://www.fmcsa.dot.gov/facts-research/systems-technology/product-guides/wireless-mobile-comm.htm> [Nov. 4, 2010a].
- Federal Motor Carrier Safety Administration (FMCSA), Technology Division, "Tire Pressure Monitoring Systems," Safety technology product guide [Online]. Available: <http://www.fmcsa.dot.gov/facts-research/systems-technology/product-guides/tire-pressure.htm> [Nov. 1, 2010b].
- Federal Motor Carrier Safety Administration (FMCSA) and ICF International, Regulatory Impact Analysis for HOS Options, FMCSA-2004-19608-2529, FMCSA, Washington, D.C., Dec. 7, 2007.
- Flanigan, C., "Tire Pressure Monitoring and Maintenance System Field Operational Test," Presentation in *Talking Safety Technology Webinar*, FMCSA Technology Division, Federal Motor Carrier Safety Administration, Washington, D.C., May 12, 2010.
- Freund, D. M., S. J. Shaffer, L. W. Loy, and L. W. Minor, "Utilizing Future Vehicle Technology to Improve Safety," *Future Truck and Bus Research Opportunities, TRB Conference Proceedings 38*, Transportation Research Board of the National Academies, Washington, D.C., 2006.
- Gou, M., O. Bellavigna, B. Clement, and S. Birikundavyi, "Causal and Contributory Factors in Large Truck Collisions," *Proceedings of the Second International Large Truck Safety Symposium*, E01-2510-002-00, University of Tennessee Transportation Center, Knoxville, Oct. 6–8, 1999, pp. 123–128.
- Haddon, W., "Advances in the Epidemiology of Injuries as a Basis for Public Policy," *Public Health Reports*, Vol. 95, No. 5, 1980, pp. 411–421.
- Harwood, D., "Roadway Design Comments," In *Future Truck and Bus Research Opportunities, TRB Conference Proceedings 38*, Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 85–86.
- Hickman, J. S., R. J. Hanowski, and J. Bocanegra, *Distraction in Commercial Trucks and Buses: Assessing Prevalence and Risk in Conjunction with Crashes and Near-Crashes*, FMCSA Report No. FMCSA-RRR-10-049, Federal Motor Carrier Safety Administration, Washington, D.C., Sep. 2010.
- Hickman, J. S., R. R. Knipling, R. L. Olson, M. Fumero, R. J. Hanowski, and M. Blanco, *Phase I—Preliminary Analysis of Data Collected in the Drowsy Driver Warning System Field Operational Test: Task 5, Phase I Data Analysis*, for the FMCSA under NHTSA Contract DTNH22-00-C-07007, TO #21, Washington, D.C., Sep. 30, 2005.
- Hodges, S., "Putting the 'Gee!' in GPS: Wireless Navigation Aids Able to Show Traffic Updates—With Limitations," *Transport Topics iTech*, June 2008, reprinted in *The Best of Transport Topics Magazines*, 4th ed., 2009, pp. 19–22.
- Holguin-Veras, J., K. Ozbay, A. Kornhauser, A. Shorris, and S. Ukkusuri, *Integrative Freight Demand Management in the New York City Metropolitan Area*, Rensselaer Polytechnic Institute draft report, U.S. DOT Cooperative Agreement DTOS59-07-H-0002, Aug. 2010.
- Howarth, H., S. Alton, N. Arnopolskaya, L. Barr, and T. Di Domenico, *Driver Issues: Commercial Motor Vehicle Safety Literature Review*, FMCSA-PSV-07-006, U.S. DOT Volpe National Transportation Systems Center, Cambridge, Mass., June 2007.
- International Road Transport Union (IRU), *Second Report on Road Transport Best Industry Practices*, Geneva, Switzerland, 2003 [Online]. Available: http://www.iru.org/en_bookshop_item?rewrite_sticky=bookshop-display-action&id=3.
- ITS America, "Smart Mobility for a 21st Century America; Strategies for Maximizing Technology to Minimize Congestion, Reduce Emissions, and Increase Efficiency," White Paper. ITS American, Washington, D.C., Oct. 2010.
- Khattak, A. J., A. C. Siefkes, and F. M. Council, "Are Truck-Involved Crashes More Frequent and Severe During Work Zones?" *Proceedings of the Second International Large Truck Safety Symposium*, E01-2510-002-00, University of Tennessee Transportation Center, Knoxville, Oct. 6–8, 1999, pp. 211–225.
- Knipling, R. R., *Sleeper Berth Use in Two-Up Driving Operations*, Research report prepared for the Australia National Transport Commission, Feb. 2006 [Online]. Available: <http://www.ntc.gov.au/filemedia/Reports/HVDFSleepBerthUse2upDrivOpsFeb06.pdf>.
- Knipling, R. R., *Safety for the Long Haul: Large Truck Crash Risk, Causation, & Prevention*, American Trucking Associations, Arlington, Va., 2009.
- Knipling, R. R. and J. Bocanegra, *Comparison of Combination-Unit Truck and Single-Unit Truck Statistics from the LTCCS*, FMCSA and Volpe Center Project Report, Washington, D.C., 2008.
- Knipling, R. R., S. V. Burks, K. M. Starner, C. P. Thorpe, and G. Bergoffen, *CTBSSP Synthesis Report on Driver Selec-*

- tion Tests & Measurements*, Transportation Research Board of the National Academies, Washington, D.C., 2011.
- Knipling, R. R., J. S. Hickman, and G. Bergoffen, *CTBSSP Synthesis 1: Effective Commercial Truck and Bus Safety Management Techniques: A Synthesis of Safety Practice*. Transportation Research Board of the National Academies, Washington, D.C., 2003.
- Knipling, R. R., R. J. Hanowski, J. S. Hickman, R. L. Olson, T. A. Dingus, and R. J. Carroll, "Exposure-risk Analysis of Large Truck Naturalistic Driving Data," *Proceedings of the 2005 Truck and Bus Safety and Security Symposium*, Alexandria, Va., Nov. 14–16, 2005.
- Kreeb, R. M., B. T. Nicosia, and P. J. Fisher, *Commercial Vehicle Tire Condition Sensors*, FMCSA Report No. FMCSA-PSV-04-002, Federal Motor Carrier Safety Administration, Washington, D.C., 2003.
- Leone, D., "Safety Concerns Driver Interest in Truck-Specific GPS," *Transport Topics iTech*, Aug. 9, 2010, pp. A5–A16.
- Mayhew, C. and M. Quinlan, "Economic Pressure, Multi-Tiered Subcontracting and Occupational Health and Safety in Australian Long-Haul Trucking," *Employee Relations*, Vol. 28, 2006, pp. 212–229.
- McQuire, T., "Wellness Framework: The Four Rs," *International Conference on Commercial Driver Health and Wellness*, Transportation Research Board, Washington, D.C., Nov. 8–10, 2010.
- Meyer, M. D., *Crashes vs. Congestion—What's the Cost to Society?* Cambridge Systematics, Inc., for the American Automobile Association, Cambridge, Mass., Mar. 2008.
- Montufar, J., J. Regehr, G. Rempel, and R. V. McGregor, *Long Combination Vehicle (LCV) Safety Performance in Alberta: 1999–2005*, Final Report for Alberta Infrastructure and Transportation, Alberta, On., Canada, Apr. 2007.
- Moonesinghe, R., A. Longthorne, U. Shankar, S. Singh, R. Subramanian, and J. Tessmer, *An Analysis of Fatal Large Truck Crashes*, NHTSA National Center for Statistics and Analysis, DOT HS 809 569, National Highway Traffic Safety Administration, Washington, D.C., Mar. 2003.
- Moore, B., "An Integrated Approach to the Regulation of Heavy Vehicles," National Transport Commission Australia, *23rd World Roads Congress*, Paris, France, Sep. 17–21, 2007.
- Murray, D. C., K. Wahl, and R. M. Brewster, *Safety by Design: Optimizing Safety in Highway Work Zones*, American Transportation Research Institute, Alexandria, Va., Sep. 2005.
- Murray, W., S. Ison, P. Gallemore, and H. S. Nijjar, "Effective Occupational Road Safety Programs: A Case Study of Wolseley," *Transportation Research Record: Journal of the Transportation Research Board*, No. 2096, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 55–64.
- Murray, W., S. Newman, B. Watson, J. Davey, and C. Schonfeld, "Evaluating and Improving Fleet Safety in Australia," CARRS-Q, Queensland University of Technology, for the Australian Transport Safety Bureau, Apr. 2003 [Online]. Available: <http://eprints.qut.edu.au/7952/1/7952.pdf> http://publications/2003/eval_fleetsafe.aspx.pdf.
- National Highway Traffic Safety Administration (NHTSA), *Traffic Safety Facts 2008*, DOT HS 811 170, Washington, D.C., 2010 [Online]. Available: <http://www-nrd.nhtsa.dot.gov/Pubs/811170.pdf>.
- National Transportation Safety Board (NTSB), *Fatal Highway Accidents on Wet Pavement—The Magnitude, Location and Characteristics*, Special Study, NTSB-HSS-80-1, NTSB, Washington, D.C., 1980.
- New York City Department of Transportation, "NYC DOT Pilot Program Finds Economic Savings, Efficiencies for Truck Deliveries Made During Off-hours," July 1, 2010 [Online]. Available: http://www.nyc.gov/html/dot/html/pr2010/pr10_028.shtml.
- O'Neil, T. R., J. R. Krueger, S. B. Van Hemel, and A. I. McGowan, *Effects of Operating Practices on Commercial Driver Alertness*, Trucking Research Institute, for the FHWA Office of Motor Carriers, Report No. FHWA-MC-99-140, Washington, D.C., Jan. 1999.
- Reiskin, J. S., "Fleets Seek New Technology to Aid Safety, Savings, Fuel," *Transport Topics*, Nov. 29, 2010, pp. 5, 25.
- Rossetti, M. A. and M. Johnsen, "Impacts of Climate Change and Weather on Commercial Motor Vehicles," *American Meteorological Society Annual Meeting*, Jan. 24, 2008 [Online]. Available: <http://ams.confex.com/ams/pdfpapers/134596.pdf>.
- Runge, J. W., "Public Health and the Epidemic of Motor Vehicle Crashes," American Public Health Association Meeting, Nov. 18, 2003.
- SAFED, *Safe and Fuel Efficient Driving* [Online]. Available: www.safed.org.uk [Feb. 16, 2010].
- Safe Road Systems [Online]. Available: <http://www.saferoadsystems.com> [Nov. 15, 2010].
- Schrank, D. and T. Lomax, *The 2009 Urban Mobility Report*, DOT Grant No. DTRT06-G-0044, Texas Transportation Institute, College Station, Sep. 2009.
- Shackelford, S. and D. C. Murray, *Electronic Onboard Recorder Adoption in the Trucking Industry: Issues and Opportunities*, American Transportation Research Institute, Arlington, Va., Sep. 2006.
- Shinar, D., *Traffic Safety and Human Behavior*, Elsevier, Amsterdam, The Netherlands, 2007.
- Short, J., "Impact of Highway and Interstate Funding Policy Decisions on Truck Safety and Truck-Involved Crashes," *Future Truck and Bus Research Opportunities, TRB Conference Proceedings 38*, 2006, pp. 87–91.
- Short, J., R. Pickett, and J. Christianson, *Freight Performance Measures Analysis of 30 Freight Bottlenecks*, American Transportation Research Institute, Arlington, Va., 2009 [Online]. Available: [http://knowledge.fhwa.dot.gov/cops/pm.nsf/All+Documents/C28180E0EA33E0F68525756F00782804/\\$File/ATRI%20Freight%20Bottleneck%20Analysis_L.PDF](http://knowledge.fhwa.dot.gov/cops/pm.nsf/All+Documents/C28180E0EA33E0F68525756F00782804/$File/ATRI%20Freight%20Bottleneck%20Analysis_L.PDF).
- Smith, C. D. and C. Roberts, *The Adoption of Technologies, Policies, and Systems for Improving Fleet Fuel Performance*, Center for Transportation Research and Education, Iowa State University, Ames, MTC Project 2006-04, Nov. 2007.

- Staplin, L., K. W. Gish, L. E. Decina, and R. M. Brewster, *Commercial Motor Vehicle Driver Retention and Safety*, Final Report, FMCSA Contract No. DTMC75-01-P-00027, Federal Motor Carrier Safety Administration, Washington, D.C., Sep. 2002.
- Starnes, M., *LTCCS: An Initial Overview*, NHTSA National Center for Statistics and Analysis, DOTR HS 810 646, National Highway Traffic Safety Administration, Washington, D.C., Aug. 2006.
- Stock, D., *I-95 Corridor Coalition Field Operational Test 10: Coordinated Safety Management; Volume I: Best Practices in Motor Carrier Safety Management*, PENNDOT Final Report, Pennsylvania Transportation Institute, University Park, Aug. 2001.
- Strah, T. M., "Telematics: Converging at the Truck," *Transport Topics iTech*, Aug. 2007, reprinted in *The Best of Transport Topics Magazines*, 4th ed., 2009, pp. 39–41.
- Symmons, M. S. and G. Rose, "Ecodriving Training Delivers Substantial Fuel Savings for Heavy Vehicle Drivers," *Driving Assessment 2009 Conference*, Big Sky, Mont., June 2009.
- Tardif, L.-P. and R. Barton, *Evaluating Reductions in Greenhouse Gas Emissions Through the Use of Turnpike Double Truck Combinations, and Defining Best Practice for Energy-Efficiency*, L-P Tardif & Associates Inc., in association with Ray Barton Associates Ltd., Report for the Canadian Trucking Alliance, Dec. 2006.
- U.S.DOT Office of Public Affairs, "U.S. Transportation Secretary Ray LaHood Kicks Off Second National Distracted Driving Summit," Press Release 175-10, Sep. 21, 2010.
- U.S. Government Accountability Office (GAO), *More Could Be Done to Determine Impact of Excessive Loading and Unloading Wait Times on Hours of Service Violations*, GAO-11-198, GAO, Washington, D.C., Jan. 2011.
- Van Order, D., D. Skorupski, R. Stinebiser, and R. Kreeb, *Fleet Study of Brake Performance and Tire Pressure Sensors*, Technical Report, FMCSA-PSV-09-001, Federal Motor Carrier Safety Administration, Washington, D.C., July 2009.
- Walonick, D. S., *A Selection from Survival Statistics*, Stat-Pac, Inc., Bloomington, Minn., 2010.
- Wang, J. S., R. R. Knipling, and L. J. Blincoe, "The Dimensions of Motor Vehicle Crash Risk," *Journal of Transportation and Statistics*, Vol. 2, No. 1, May 1999, pp. 19–43.
- Williams, A. F., "The Haddon Matrix: Its Contribution to Injury Prevention and Control," presented at the Third National Conference on Injury Prevention and Control, Brisbane, Queensland, Australia, May 9–12, 1999.
- Wright, I. D., G. Veith, and D. Tsolakis, *Productivity Implications of Heavy Vehicle Safety Programs*, Austroads Publication No. Ap-R263/05, Austroads, Sydney, Australia, 2005.
- Zacharatos, A., J. Barling, and R. D. Iverson, "High-Performance Work Systems and Occupational Safety," *Journal of Applied Psychology*, Vol. 90, 2005, pp. 77–93.
- Zaloshnja, E. and T. Miller, *Unit Costs of Medium & Heavy Truck Crashes*, Final Report, Pacific Institute for Research and Evaluation for FMCSA, Mar. 2007 [Online]. Available: <http://ai.volpe.dot.gov/carrierresearchresults/pdfs/crash%20costs%202006.pdf>.
- Zarkadoula, M., G. Zoidis, and E. Tritopoulou, "Training Urban Bus Drivers to Promote Smart Driving: A Note on a Greek Eco-Driving Pilot Program," *TR Part D: Transport and Environment*, Vol. 12, No. 6, 2007, pp. 449–451.
- Zuckerman, A., "Train Drivers for Fuel Economy," *Light and Medium Truck*, Oct. 2008, reprinted in *The Best of Transport Topics Magazines*, 4th ed., 2009, pp. 10–13.

ACRONYMS

ATRI	American Transportation Research Institute
BISC	Bus Industry Safety Council
CDL	Commercial driver's license
CFR	Code of Federal Regulations
CMV	Commercial motor vehicle
CR	Critical reason
CT	Combination-unit truck (tractor-trailer)
CVO	Commercial vehicle operations
DOT	Department of Transportation (federal, unless otherwise specified)
ECBS	Electrically controlled braking systems
EOBRs	Electric onboard recorders
ESC	Electronic stability control
FMCSR	Federal Motor Carrier Safety Regulation
GIS	Geographic Information System
GPS	Global positioning system
HOS	Hours-of-service
HPV	Higher productivity vehicle
IIHS	Insurance Institute for Highway Safety
LCV	Longer combination vehicle
LTCCS	Large Truck Crash Causation Study
LTL	Less-than truckload
NPTC	National Private Truck Council
OBSM	On-board safety monitoring
OOS	Out-of-service
PAR	Police accident report
R&D	Research and development
ROI	Return on investment
SM	Safety manager (generic term including other, similar job titles)
ST	Single-unit truck (Straight Truck)
SV	Single-vehicle [crash]
TC	Transport Canada
TCA	Truckload Carriers Association
TL	Truckload
TPMS	Tire pressure monitoring system
TRIS	Transportation Research Information Services
<i>TT</i>	<i>Transport Topics</i> (publication)
UMTRI	University of Michigan Transportation Research Institute
VMT	Vehicle-miles traveled
VTTI	Virginia Tech Transportation Institute

GLOSSARY

- Benchmarking**—To compare company practices and outcomes to those of other carriers (external benchmarking), or to track them in relation to past performance or to goals (internal benchmarking).
- Correlation**—The degree of association or predictability between two variables (e.g., height and weight) among the same group of subjects (e.g., drivers).
- Correlation coefficient**—A statistic summarizing direction and degree of association. Correlation coefficients range from -1.0 (a perfect *inverse* relation) through zero (no statistical association) to $+1.0$ (a perfect *linear* relation).
- Critical Reason (CR)**—In the LTCCS, the human, vehicle, or environmental failure leading to the Critical Event and thus to the crash. The immediate or proximal cause of a crash.
- Deadheads**—Empty backhaul trips.
- Detention**—Excessive driver delays associated with truck loading and unloading.
- Diversions**—The practice of avoiding freeway tolls by choosing alternative, untolled routes, which often are undivided highways with more traffic interaction and higher crash risks.
- Exposure**—Vehicle-miles traveled (VMT), hours driving, or other denominator to determine crash rates. Exposure data are essential for determining relative risk for different drivers, vehicle types, and driving situations.
- Haddon Matrix**—A framework for understanding and designing crash reduction strategies. The 3×3 matrix juxtaposes time frame (i.e., pre-crash, crash, and post-crash) and agent (i.e., human, vehicle, environment). Expansions of the Haddon Matrix account better for the complexities of CMV transport.
- Higher-Productivity Vehicles (HPVs)**—Vehicles with Gross Vehicle Weight Ratings (GVWRs) of more than 80,000 lb, the maximum size of standard tractor-semitrailers; includes Longer Combination Vehicles (LCVs).
- Likert scale**—Common survey technique in which answer choices are presented as numeric rating scales, often with five choices numbered from 1 to 5.
- Mean**—The arithmetic average score in a group of scores, computed by adding all the scores and dividing the sum by the number of cases.
- Median**—The middle score in a group of scores. The point or score that divides the group into two equal parts. The median is also known as the 50th percentile.
- Naturalistic driving**—Safety research in which vehicles are instrumented with video camera and various dynamic sensors. Subjects are fully informed and usually paid, but they quickly revert to driving in their normal manner. This permits observation of driving behavior and traffic events as they naturally occur.
- Navigation**—Way-finding, generally in the context of a particular A-to-B trip.
- Odds ratio**—A statistic often used to quantify relative risk or occurrence of an outcome for two different situations or groups. An odds ratio greater than 1.0 implies over-involvement (e.g., in driving incidents), whereas an odds ratio less than 1.0 implies under-involvement.
- Response bias**—The tendency, likely strong in the current surveys, for respondents to be more committed and interested in the topic than those not responding. Because of response bias and other factors, the surveys in this project should not be considered representative of larger groups (e.g., all motor carrier safety managers).
- Risk avoidance**—In this report, refers to operational practices that deploy vehicles and drivers efficiently and with safety benefits; includes safety-conscious routing (e.g., maximizing freeways, minimizing peak hour driving, assigning familiar routes) and similar deployment strategies.
- Risk factor**—Any prior factor (driver, vehicle, environment, carrier) that affects the probability of a crash.
- Risk reduction**—In the context of this report, refers to conventional carrier safety efforts to improve the safety performance of individual drivers and vehicles. This usually involves making company investments in proven interventions such as improved driver selection, training, management oversight, or vehicle safety equipment; contrasted with risk avoidance, defined earlier.
- Routing optimization**—Improvements in the efficiency of an overall pickup and delivery sequence, as in a full driver tour-of-duty or multiday trip (Bennett 2009).
- Speed limiters**—Electronic controls that limit the top powered speed of vehicles; also called speed governors.
- Speed paradox**—Although excessive speed is the biggest single proximal cause of crashes, there is generally less crash risk at higher travel speeds across the normal ranges of speed (i.e., not including overspeeding). The speed paradox demonstrates the overall positive association between travel efficiency and safety.
- Telematics**—General term encompassing onboard sensors, networks, software, GPS, and wireless communications that are becoming commonplace in today's commercial vehicles.

APPENDIX A

Project Survey Forms

APPENDIX A1: SAFETY-MANAGER QUESTIONNAIRE

APPENDIX A2: OTHER-EXPERT QUESTIONNAIRE

MOTOR CARRIER SAFETY MANAGER/HUMAN RESOURCE MANAGER SURVEY

Synthesis Study on Safety Effects of Carrier Efficiencies

Transportation Research Board CTBSSP Study MC-22

This study looks at ways that carrier efficiencies and other operational practices might affect safety, positively or negatively. Participation in this survey is **voluntary**. All respondent answers will be treated as **confidential** and aggregated with other responses in the reporting. No survey responses will be attributed to an individual. Survey respondents will receive a link to the synthesis report when it is published. *Thanks for your participation and support!*

- (1) **Factors Affecting Safety and Crash Risk:** Consider the entire fleet of North American commercial vehicles (trucks and buses). Across all these drivers and vehicles, which factors have the greatest association with crash risk? Pick **up to two (2)** of the factors below which, in your opinion, have the **greatest association** with crash risk. Circle the letter(s).
- (a) Enduring/long-term *driver traits*; e.g., age, physical abilities, medical conditions, personality, behavioral history.
 - (b) Temporary *driver states*; e.g., moods, daily circadian rhythms, effects of recent sleep, effects of recent food and fluids, effects of environmental conditions in cab, etc.
 - (c) *Vehicle* characteristics (e.g., configuration, safety equipment, load) and mechanical condition (e.g., brakes, tires).
 - (d) *Roadway characteristics and traffic conditions*; e.g., undivided versus divided highways, construction zones, traffic density, speed limits, lane restrictions, etc.
 - (e) *Weather and roadway surface conditions*; e.g., wet versus dry, road surface friction, visibility, wind, etc.
- (2) In your opinion, which **one** of the above has the **least association** with crash risk? Write letter here: _____.

Driving Situations and Operational Practices Possibly Affecting Fleet Safety

The following are driving situations or carrier operational practices which may *reduce*, *not affect*, or *improve* fleet safety. Assign each situation or practice a negative value if it decreases safety, zero if it does not affect safety, or a positive value if it improves safety. Choose one number for each. Consecutive items may represent alternative or even opposing safety strategies.

Driving Situation/Operational Practice	Reduces Fleet Safety					Improves Fleet Safety			No Opinion/Not Sure
	-3	-2	-1	0	+1	+2	+3		
(3) Reduce empty backhauls (deadheads)	-3	-2	-1	0	+1	+2	+3	X	
(4) Reduce loading/unloading delays	-3	-2	-1	0	+1	+2	+3	X	
(5) Increase routing efficiency using GPS navigation aids and/or truck routing software	-3	-2	-1	0	+1	+2	+3	X	
(6) Maximize travel on Interstates and other freeways	-3	-2	-1	0	+1	+2	+3	X	
(7) Maximize travel on low-speed roads (e.g., two-lane local roads)	-3	-2	-1	0	+1	+2	+3	X	
(8) Maximize <i>day</i> driving to avoid driver fatigue and other nighttime risks	-3	-2	-1	0	+1	+2	+3	X	
(9) Maximize <i>night</i> driving to avoid daytime traffic	-3	-2	-1	0	+1	+2	+3	X	
(10) Avoid urban rush hours and other heavy traffic situations	-3	-2	-1	0	+1	+2	+3	X	
(11) Avoid adverse weather and slick roads	-3	-2	-1	0	+1	+2	+3	X	
(12) Avoid construction zones	-3	-2	-1	0	+1	+2	+3	X	
(13) Assign familiar routes to drivers when possible	-3	-2	-1	0	+1	+2	+3	X	
(14) Use <i>fewer, larger trucks</i> (e.g., multi-trailer trucks) when possible	-3	-2	-1	0	+1	+2	+3	X	
(15) Use <i>more, smaller trucks</i> (e.g., single-unit trucks) when possible	-3	-2	-1	0	+1	+2	+3	X	
(16) Use onboard computers	-3	-2	-1	0	+1	+2	+3	X	
(17) Use mobile communication systems	-3	-2	-1	0	+1	+2	+3	X	

Which Operational Practices and Tools Do You Regularly Use?

For each of the operational practices below, please indicate **yes** or **no** whether your organization uses the practice. If **yes**, rate its overall **safety effectiveness** using the 1–5 scale provided. Circle your answer. If **no**, leave the ratings blank.

Carrier Practices:	Do you regularly use?		If “Yes,” please rate safety effectiveness:				
	Yes	No	Highly Ineffective	Ineffective	Not Sure/Neutral	Effective	Highly Effective
(18) Preventive maintenance schedule and record for each vehicle	Yes	No	1	2	3	4	5
(19) Preventive maintenance software or spreadsheets	Yes	No	1	2	3	4	5
(20) Use brokers or other services to reduce empty backhauls (deadheads)	Yes	No	1	2	3	4	5
(21) Charge extra fees to customers for excessive loading/unloading delays.	Yes	No	1	2	3	4	5
(22) Require drivers to complete a trip plan prior to trip.	Yes	No	1	2	3	4	5
(23) Use general GPS navigation/routing systems or services	Yes	No	1	2	3	4	5
(24) Use <i>truck-specific</i> navigation/routing systems or services	Yes	No	1	2	3	4	5
(25) Provide “EZ Pass” transponder and/or reimbursement of toll charges to drivers/OOs	Yes	No	1	2	3	4	5
(26) Use higher capacity vehicles (e.g., twin trailers, LCVs) when possible	Yes	No	1	2	3	4	5
(27) Use onboard computers	Yes	No	1	2	3	4	5
(28) Use mobile communications	Yes	No	1	2	3	4	5

(29) What is the relationship between carrier *efficiency* and *safety*? Circle the letter of the statement you most agree with.

- (a) Highly efficient carriers tend also to be *more safe* than other carriers.
- (b) Carrier efficiency and carrier safety are *largely unrelated* to each other.
- (c) Highly efficient carriers tend to be *less safe* than other carriers.
- (d) Don't know/no general opinion.

(30) In your fleet, what operational efficiency or other practice contributes *most* to fleet safety?

(31) **Other comments** regarding carrier efficiencies or other practices affecting fleet safety (positively or negatively):

Information about You and Your Fleet

(32) Number of years you have been a carrier Safety Manager or Human Resource Manager: _____

(33) Your total years' experience in commercial truck/bus operations: _____

(34) Approximate number of power units currently in your organizations' fleet: _____

(35) Circle *the operation type that best characterizes your fleet*

- (a) For hire: long haul/truckload
- (b) For hire: long-haul/less-than-truckload (LTL)
- (c) For hire: local/short haul (most trips <100 miles)
- (d) Private industry: long haul
- (e) Private: local/short haul (most trips <100 miles)
- (f) Passenger carrier: scheduled service
- (g) Passenger carrier: charter
- (h) Other: _____

(36) Provide your e-mail address if you would like to receive pdfs of the project report and presentation in early 2011. This information will be used for no other purpose. _____

Thank you for completing this survey!

[Questions or additional comments? E-mail the project manager at tbsafety@aol.com]

EXPERT SURVEY [Administered Online via “Survey Gizmo”]

Synthesis Study on Safety Effects of Carrier Efficiencies

Transportation Research Board CTBSSP Study MC-22

Dear Motor Carrier Safety Expert,

The Transportation Research Board (TRB) is conducting synthesis study MC-22 on *Safety Effects of Carrier Efficiencies*. This is being done for the Commercial Truck and Bus Safety Synthesis Program (CTBSSP). CTBSSP is sponsored by the Federal Motor Carrier Safety Administration and administered by TRB.

This project seeks to explore driving conditions relevant to safety and ways that truck and bus fleets can change their operational practices to reduce crash exposures and risk. In particular, the study looks at potential safety effects (good or bad) of carrier efficiencies.

This survey is being sent to [being sent to] safety professionals who are knowledgeable on this topic but who are not currently motor carrier safety managers. A separate survey form has been developed for that respondent group. If you are currently a carrier safety manager and wish to take the survey, please contact us.

Please complete and submit this survey by August 31, 2010. We estimate that it should take no more than 20 minutes to complete. If you have any questions, please contact our principal investigator, Dr. Ron Knipling at rknipling@verizon.net. Any supporting materials can be sent directly to Dr. Knipling.

Participation in the survey is voluntary. All answers provided by survey respondents will be treated as confidential and aggregated with other responses in the reporting. No survey comments or other responses will be attributed to an individual. Survey respondents will receive a link to the synthesis report when it is published.

QUESTIONNAIRE INSTRUCTIONS:

- (1) To view and print the entire questionnaire, click on this link and print using “Control p.”
- (2) To save your partial answers, click on the “Save and Continue Later” link in the upper right corner of your screen. A link to the partial survey will be e-mailed to you.
- (3) To view and print your answers before submitting the survey, click forward to the page following the last question (Question 22). Print using “control p.”
- (4) To submit the survey, click on “Submit” on the last page.

Thanks for your help!

This study looks at ways that carrier efficiencies and other operational practices might affect safety, positively or negatively. Participation in this survey is **voluntary**. All respondent answers will be treated as **confidential** and aggregated with other responses in the reporting. No survey responses will be attributed to an individual. Survey respondents will receive a link to the synthesis report when it is published. *Thanks for your participation and support!*

- (1) **Factors Affecting Safety and Crash Risk:** Consider the entire fleet of North American commercial vehicles (trucks and buses). Across all these drivers and vehicles, which factors have the greatest association with crash risk? Pick **up to two (2)** of the factors below which, in your opinion, have the **greatest association** with crash risk. Circle the letter(s).
 - (a) Enduring/long-term *driver traits*; e.g., age, physical abilities, medical conditions, personality, behavioral history.
 - (b) Temporary *driver states*; e.g., moods, daily circadian rhythms, effects of recent sleep, effects of recent food and fluids, effects of environmental conditions in cab, etc.
 - (c) *Vehicle characteristics* (e.g., configuration, safety equipment, load) and mechanical condition (e.g., brakes, tires).
 - (d) *Roadway characteristics and traffic conditions*; e.g., undivided versus divided highways, construction zones, traffic density, speed limits, lane restrictions, etc.
 - (e) *Weather and roadway surface conditions*; e.g., wet versus dry, road surface friction, visibility, wind, etc.
- (2) In your opinion, which **one** of the above has the **least association** with crash risk? [Choices re-presented].

Driving Situations and Operational Practices Possibly Affecting Fleet Safety

The following are driving situations or carrier operational practices which may *reduce*, *not affect*, or *improve* fleet safety. Assign each situation or practice a negative value if it decreases safety, zero if it does not affect safety, or a positive value if it improves safety. Choose one number for each. Consecutive items may represent alternative or even opposing safety strategies.

Driving Situation/Operational Practice	Reduces Fleet Safety			No Effect on Safety			Improves Fleet Safety		No Opinion/ Not Sure
	-3	-2	-1	0	+1	+2	+3		
(3) Perform regular vehicle preventive maintenance	-3	-2	-1	0	+1	+2	+3	X	
(4) Use brokers and other services to reduce empty backhauls (deadheads)	-3	-2	-1	0	+1	+2	+3	X	
(5) Reduce loading/unloading delays	-3	-2	-1	0	+1	+2	+3	X	
(6) Increase routing efficiency using GPS navigation aids and/or truck routing software	-3	-2	-1	0	+1	+2	+3	X	
(7) Maximize travel on Interstates and other freeways	-3	-2	-1	0	+1	+2	+3	X	
(8) Maximize travel on low-speed roads (e.g., two-lane local roads)	-3	-2	-1	0	+1	+2	+3	X	
(9) Maximize <i>day</i> driving to avoid driver fatigue and other nighttime risks	-3	-2	-1	0	+1	+2	+3	X	
(10) Maximize <i>night</i> driving to avoid daytime traffic	-3	-2	-1	0	+1	+2	+3	X	
(11) Avoid urban rush hours and other heavy traffic situations	-3	-2	-1	0	+1	+2	+3	X	
(12) Avoid adverse weather and slick roads	-3	-2	-1	0	+1	+2	+3	X	
(13) Avoid construction zones	-3	-2	-1	0	+1	+2	+3	X	
(14) Assign familiar routes to drivers when possible	-3	-2	-1	0	+1	+2	+3	X	
(15) Use <i>fewer, larger trucks</i> (e.g., multi-trailer trucks) when possible	-3	-2	-1	0	+1	+2	+3	X	
(16) Use <i>more, smaller trucks</i> (e.g., single-unit trucks) when possible	-3	-2	-1	0	+1	+2	+3	X	
(17) Use onboard computers	-3	-2	-1	0	+1	+2	+3	X	
(18) Use mobile communication systems	-3	-2	-1	0	+1	+2	+3	X	

(19) Additional comments regarding roadway/operational risk factors or carrier efficiencies affecting crash risk.

(20) Choose the statement below you most agree with.

- Highly efficient carriers tend also to be *more safe* than other carriers.
- Carrier efficiency and carrier safety are *largely unrelated* to each other.
- Highly efficient carriers tend to be *less safe*.
- Don't know/no general opinion.

Information about You

(21) Approximately how many years of professional experience do you have relating to motor carrier safety? _____

(22) Please indicate **all** experience areas below for which you have one year or more experience relating to motor carrier safety:

- Government enforcement
- Other government (e.g. rulemaking, policy)
- Industry trade association
- Commercial driver
- Carrier safety director/manager
- Other carrier management position
- Safety consultant or vendor to fleets
- Accident investigation/data analysis
- Motor carrier safety research
- Journalist
- Driver trainer/training development
- Insurance for motor carriers
- Other: _____

["SUBMIT SURVEY" BOX]

Abbreviations used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI-NA	Airports Council International-North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation