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16. ABSTRACT
This project developed, designed, built and tested a proof of concept system to provide an Onboard Safety Monitoring System for a Class 8 Commercial Truck. The system was built into and tested in a Freightliner Class 8 truck. The project used a Systems Engineering approach using the International Counsel of Systems Engineers (INCOSE) Vee model, and developed the documents in the model.

The reports include:
- Concept of Operations
- Systems Engineering Management Plan (SEMP)
- Risk Management Plan
- Engineering Requirements
- Causal Factors Report

All developed during the project.

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## DISCLAIMER STATEMENT

# Onboard Driver Monitoring and Feedback:
# Concept of Operations

# 1.0 ONBOARD DRIVER MONITORING BACKGROUND

## 1.1 Introduction

Each year over 450,000 large trucks are involved in crashes resulting in about 5000 fatalities and 120,000 injuries according to the most recent compilation of traffic safety facts released by the National Highway Traffic Safety Administration (NHTSA). Overall, crashes involving large trucks comprise 4.1 percent of all crashes, but they also contribute to 12 percent of all fatalities (or one out of every nine). Furthermore, more than 85 percent of the time, the fatality was not an occupant of the truck (NHTSA, 2003).

Each year, the University of Michigan Transportation Research Institute (UMTRI) publishes an in-depth analysis of trucks involved in fatal accidents. However, these studies reveal nothing extraordinary about the accident conditions when large trucks are involved. Nearly two-thirds of the crashes occur in rural areas with almost 55 percent occurring on a state or U.S. highway and 25 percent occurring on interstates. Almost two-thirds of the fatalities occurred during daylight and over 80 percent occurred on dry roads during normal weather (Matteson, Blower, and Woodrooffe, 2004).

The there are a few statistics that do stand out about the drivers of large trucks involved in crashes. First, 96 percent of the drivers of large trucks involved in fatal crashes were male, which is probably not surprising given the distribution of men and women in the profession. Fatigue, although often discussed and highly researched in long haul trucking, was only reported as a factor in 1.5 percent of the fatal crashes (Matteson, Blower, and Woodrooffe, 2004). Finally, only about 1 percent of the truck drivers involved in fatal crashes had a blood alcohol concentration greater than 0.08 g/dl (the legal limit in many states), whereas 22 percent of the drivers of cars and SUVs involved in fatal crashes were reported as intoxicated at the time of the crash (NHTSA, 2003).

Overall, the crash statistics reveal nothing extraordinary about the types of crashes involving trucks and truck drivers, other than the fact that fatalities occur more often when large trucks are involved, which is not surprising given the large disparity in size and mass between cars and trucks. Furthermore, most of the recent research aimed at understanding large truck crash causation has revealed that the actions of the drivers of the cars contribute more often to the crash than do those of the truck driver (Kostyniuk, Streff, and Zakrajsek, 2002; Stuster ,1999; and Blower, 1998). This sentiment has also been repeated by truck drivers themselves such as during the focus groups conducted by Roetting, Huang, and McDevitt (2003). However, this is not to say that truck drivers are always completely without fault, or that driver monitoring and feedback would provide no benefits.

In fact, driver monitoring and feedback may prove to be extremely beneficial, especially for younger or novice truck drivers. It has been shown that novice drivers are overly represented in crash statistics, and that novice truck drivers who were involved in crashes were more likely to frequently exhibit excess speed or overly aggressive driving such as following too closely. They were also more likely to exhibit signs of possible attentional overload or loss of vehicle control (Blower, 1996). All of these behaviors could be candidates for driver monitoring and feedback.

Recent analysis of instrumented truck studies (Knipling 2005) has also given weight to the notion that individual differences and behaviors play a large role in crash risk. According to surveys, fleet managers often estimate that their worst 10 percent of drivers account for up to 50 percent of their fleet risk, and this estimate was supported in a critical incident analysis of the instrumented vehicles. In this study the worst 6 drivers, accounting for only 12 percent of the driving time, were responsible for 38 percent of the critical incidents. In contrast, the best 25 drivers, accounting for 63 percent of the driving time, were only responsible for 16 percent of the critical incidents. Onboard driver monitoring and feedback may be one way to objectively identify high risk drivers, and help them to curb risky driving behavior.

### 1.2 Driver Monitoring in the Context of the Behavior-Based Safety Approach

The concept of operator (driver) monitoring is neither new, nor limited specifically to the trucking industry. Sherry (2001) identified and compared operator monitoring systems used in the maritime, air freight, motor carrier, and rail industries. A more recent paper (Lotan and Toledo, 2005) discussed a pilot program in Israel which would provided driver monitoring and feedback for teen drivers.

The general case for truck driver monitoring in the trucking industry has already been made through research sponsored by the Federal Motor Carrier Safety Administration (FMCSA) and is best summarized in a technical brief (Behavioral Science and Technology, Inc., 2000). In its most simplistic form, the behavior-based safety approach is a method for improving safety, by which, behaviors critical to safety are identified and monitored. Safe behavior is rewarded and unsafe behavior is discouraged and improved upon, thereby proactively improving overall safety.

While strict driver training programs, vehicle safety inspections, and the constant monitoring of crash statistics have all been means for monitoring safety in the past, the advent of cheap sensing technologies has made possible the continuous monitoring speed, headway, and other driving parameters. This new technology provides the fundamentals to enable a true behavior-based safety approach. Implementing an onboard driver-monitoring behavior-based safety approach requires three steps:

1. Identify behaviors which may be precursors to increased crash rates.
2. Determine cost-effective ways to monitor safe and unsafe behaviors.
3. Determine the best way to provide the driver with feedback which rewards safe behavior and discourages unsafe behavior.
4. Establish management and driver acceptance to the program.

### 1.3 Driver Monitoring Research Review

There is much literature devoted to the many issues surrounding truck and truck driving safety, all of which may can be both relevant and tangential to the concept of onboard driver monitoring, and much of that literature is discussed throughout the various sections of this report. However, there have only been about three major published studies which have specifically examined onboard driver monitoring systems in the trucking industry. All three studies primarily focused on the issues of management and driver acceptance of onboard monitoring, in the context of improving safety.  In the first study, Sherry (2001) interviewed both management and operators in the maritime, air freight, motor carrier, and rail industries.  At the time, many of the onboard monitoring COTS devices reviewed later in this report were in existence and in use by the companies he interviewed.  However, management acceptance of onboard monitoring was mostly concentrated around the issues of reducing engine idle time and fuel consumption or accident/event recording.  Most management incentives based on the monitoring and feedback devices were given for reducing engine idle time.

From driver interviews, it was reported that 42 percent of the drivers would have no problems with a driver monitoring system, but almost 58 percent felt that the in-vehicle monitoring systems had been used to unfairly discipline drivers.  Drivers were more accepting of systems that included some sort of collision avoidance system or provided additional tangible benefits, such as reducing paperwork and logging requirements.  It was also reported that driver perceived as "good" drivers were more positive and accepting towards the monitoring systems than were drivers that were considered more problematic.  Summarizing from interviews across industries, Sherry (2001) concluded that several factors (outlined in Table 1-1) were frequently cited in support of or against operator monitoring systems.

Table 1-1.  Factors Influencing Onboard Monitoring Acceptance.

| Positive Influences on Acceptance | Negative Influences on Acceptance |
|---|---|
| Improved safety (if the technology lives up to its promise). | Fear of embarrassment or self-consciousness at being monitored all the time. |
| Liability protection (such as when the driver is not at fault for a crash). | Fear of liability or unfair accountability on the part of drivers such as being determined as responsible for a crash. |
| Efficiency (such as reducing paperwork). | Concern that the monitoring parameters are not indicators of safety. |
| Monetary incentives. | Misuse of the collected data. |

Despite the potential pitfalls with operator acceptance, Knipling, Hickman, and Bergoffen (2003) found support for driver monitoring among nearly 33 percent of trucking industry safety managers.  In their survey, 36 percent of the respondents reported using some form of driver monitoring system with management review and feedback, and 33 percent of the respondents ranked driver monitoring and feedback as one of their "Top Five" choices for solutions to help improve safety.  Interestingly, when given the option of driver monitoring without management review (thus insuring driver privacy), only 9 percent of the safety managers ranked this option in their "Top Five" and the option fell overall to last place (out of 28 solutions).  Most industry experts and carrier safety managers seemed to agree that driver monitoring without management review would be ineffective.

Two recent studies by Roetting, Huang, and McDevitt (2003 and 2005) extensively examined the topic of truck driver monitoring and feedback from the driver's perspective.  In the first study (2003), a total of 66 long and short haul drivers, supervisors/managers, and insurance industry safety professionals participated in 9 focus groups.  These focus groups reported similar opinions as those described above.  Drivers generally felt that driver monitoring could potential safety benefits and possibly vindicate the driver in the even of an incident or crash.  However, privacy concerns and mistrust over the use of data were also voiced. Drivers were also concerned that feedback would be primarily negative and lead to programs focused on punishments, as opposed to incentives which reward good driving behavior.

The second study, Roetting, Haung, and McDevitt (2005), surveyed 239 long and short haul drivers throughout 40 states and Canada. Drivers were generally positive towards the concept of feedback with less than half of the drivers surveyed (42 percent) responding that they were currently getting adequate feedback on their driving. Similar to the earlier focus groups, more than half the of the drivers (59 percent) felt that positive feedback would be more useful than negative feedback, and 56 percent felt that the greatest potential benefit of in-vehicle monitoring was defending the driver in the event of a crash. Unsurprisingly, the greatest concern found in the survey was over the issue of privacy. Over two-thirds or 65 percent of the survey respondents were concerned with the possibility that the data collected by the onboard monitoring system might be misused.

The three studies outlined above basically came to the same conclusions. Truck drivers were not universally opposed to the concept of onboard monitoring and feedback, and the issues surrounding privacy and misuse of the data being collected were of primary concern. The studies all also tended to reveal that acceptance was a function of perceived benefit. The more benefit the drivers saw in the individual system, the more positive they were towards accepting the overall concept of onboard monitoring.

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## 2.0 ONBOARD DRIVER MONITORING COTS REVIEW

### 2.1 COTS Overview

A search for commercial off-the-shelf (COTS) onboard truck driver monitoring systems turned up six major manufacturers: XATA, Delphi, Accident Prevention Plus, Cadec, QualCOMM, and DriveCam. These companies have been releasing on-board monitoring (OBM) products since as early as 2000. The features promoted in OBM products include real-time location, delivery status, fuel performance, and driver logs. In general, they emphasize savings on fleet operations and maintenance costs.

An overview of a typical onboard driver monitoring system is shown in Figure 2-1. The OBM system generally consists of three major components: sensors, a processing unit, and feedback devices. The most commonly-used sensors include the speedometer, tachometer, odometer, throttle angle encoder, GPS receiver, accelerometer, and steering encoder.

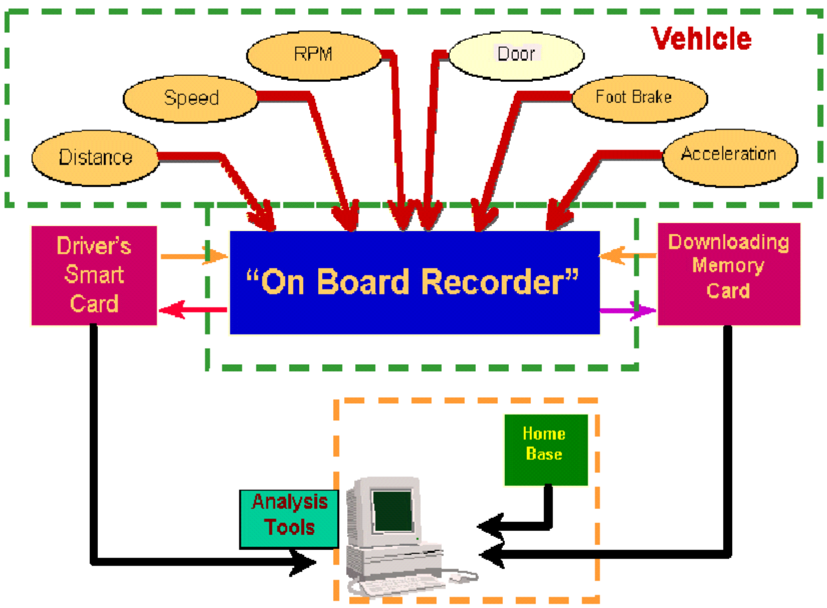


Figure 2-1. Typical OBM System[1]

By employing these sensors, the COTS systems measure the driver performance by monitoring signal use, position, speed, acceleration, and vehicle mechanical states, e.g. engine rpm, throttle angle, brake pressure, and so on. All these systems can be installed in a vehicle easily. Most of them also provide advanced driver identification system to avoid unauthorized use of the vehicle, but, there are some basic feature differences between systems as illustrated in Table 2-1.

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[1] This figure and the information on the Accident Prevention Plus AP+ series products were from the NHTSA website at the following URL: http://www-nrd.nhtsa.dot.gov/edr-site/uploads/accident_prevention_plus.pdf

Table 2-1. Basic feature comparison among these products.

| Company | Features | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Preventative maintenance monitoring | Event recording using camcorder | Remote deceleration and shutdown | Real-time asset tracking | GPS-based “geo-fencing” | Driver identification | Trailer Door security | Wireless |
| XATA | × | | | × | | × | | |
| Delphi | × | | × | × | × | × | × | |
| APPlus | | | | | | × | | |
| Cadec | | | | | × | | × | × |
| QualCOMM | | | | × | | | | × |
| DriveCAM | | × | | | | × | | |

Feedback can be provided to the driver either in real-time or after the data has been downloaded and analyzed. Real-time feedback is typically provided to the drivers through displays or speakers. Table 2-2 compares the feedback methods employed across systems.

Table 2-2. Comparison chart of feedback approaches among these products.

| Company | Feedback Device | | |
|---|---|---|---|
| | Text messaging system | Audible and visual warnings | Offline processing |
| XATA | × | | |
| Delphi | × | | |
| APPlus | | | × |
| Cadec | × | × | |
| QualCOMM | × | | |
| DriveCAM | | | × |

## 2.2 Individual COTS Systems Descriptions

### *2.2.1 XATA*

XATA’s OBM systems is primarily advertised for fleet maintenance, driver productivity, fuel economy, and safety and security concerns. The functions provided by this system include: (1) preventative maintenance monitoring, (2) onboard electronic logs, (3) real-time asset tracking, (4) monitor speeds, rapid stops or diagnostic warnings, (5) reconstruct accidents with Black Box data, (6) two-way driver messaging, and (7) electronic safety monitoring. Their systems incorporate GPS, speedometer, tachometer, odometer, fuel rate sensor, throttle position, braking (on/off only), clutch (on/off only). One advantage of the two-way messaging system is that the fleet manager can instantly communicate with the driver.

### *2.2.2 Delphi’s TruckSecure*

Delphi’s TruckSecure system is a fleet management tool that is advertises as a means to reduce the possibility of cargo trucks being used to threaten homeland security. The functions provided by this system include: (1) GPS-based positioning, routing, guidance, and “geo-fencing”, (2) asset tracking, maintenance, and productivity, (3) driver identification to prevent unauthorized use, (4) capability of gradually decelerating the vehicle to a stop and disabling the engine (remote deceleration and shutdown), and (5) trailer door security. The installed sensors include GPS, speedometer, and odometer. This system includes a small display and voice activation.

### *2.2.3 Accident Prevention Plus*

The main goals of APP system are to provide security for unauthorized use of vehicle and monitor vehicle operational data for accident prevention. Other goals include use for driver training, driver evaluation, and maintenance purposes. More specifically, their system can: (1) prevent unauthorized use of a vehicle, (2) monitor operational data (speed, engine speed, fuel consumption, acceleration/deceleration, gear position, brake on/off, lights on/off), (3) record 50 sec. before and 10 sec. after an accident. The operational data that is collected includes driving chronologies, idling chronologies, 20 most recent speed violations, maximum speed, maximum acceleration/deceleration, speed histograms, engine speed histograms, brake intensity histograms, brake occurrence, speed ranges, and gear position histograms. The system also records distance driven, maximum speed, and the number of driving periods above a selected duration. The employed sensors include speedometer, accelerometer, tachometer, fuel rate sensor, gear position sensor, braking (on/off), lights (on/off). This system does not include any interface to interact with the driver as it functions mostly as a “black box” recording data for off-line analysis.

### *2.2.4 Cadec*

The purpose of the Cadec’s Mobius TTS system is to provide a paperless tracking and delivery system; however, it has additional features concerning safety, security, and government logging compliance. Audible and visual warnings from the onboard computer help keep the drivers informed and alert so they can maintain safe vehicle handling practices. This system includes the following features: (1) wireless communication, (2) trailer temperature tracking, (3) trailer door tracking (open or closed for security), (4) route tracking, (5) coaching driver to adhere to company standards via display and audio, and (6) border crossing notification (US only). The installed sensors consist of speedometer, odometer, GPS, and tachometer. A touch screen display is used to communicate with the driver. The onboard computer can give audible and visual warnings to alert the driver.

### *2.2.5 QualCOMM*

The purpose of QualCOMM’s SensorTRACS is to send on-board sensor information to dispatch over the air to improve driver performance and safety and to analyze the fleet productivity and operation. The system proclaims that the advantage of the wireless communication is that data can be collected without driver intervention and that the fleet management team can feedback on driver performance near real-time. This system can: (1) increase fuel savings by reducing over-idle, over-revving, and excessive speed and (2) reduce engine wear and hard braking. The employed sensors include speedometer, odometer, throttle position sensor, and tachometer. This system uses text messages on a display to alert the driver.

### *2.2.6 DriveCam*

The main purpose of the DriveCam's system is safety and driver training. The system integrates video technology and management software to identify high-risk driving habits, particularly, it records large g-force events such as collisions. Their system can record 10 seconds of audio and video both before and after a large g-force event or accident. The g-force threshold is adjustable and can be adapted to different vehicles. The employed sensors include accelerometers and camcorders, which are used to record events and accidents. No real-time feedback devices are installed to interact with the driver.

## 2.3 COTS Review Summary and Conclusions

These COTS systems generally focus on fleet maintenance and saving on operations costs, but many have features related to security or driver monitoring and safety Generally, as a result, these systems monitor driver behaviors from the perspective of the vehicle's mechanical conditions and motions.

The analysis and interpretation of the gathered data is useful only if the employed algorithms take human factors into consideration. However, these products are not comprehensive from the standpoint of monitoring safety related driver behavior.

## 3.0 METHOD

The end goal of this document is to develop a concept of operations for an ideal onboard driver monitoring system for use in commercial heavy vehicles. As discussed earlier, there are four steps to a implementing a behavior based safety approach using onboard driver monitoring:

1. Identify unsafe behaviors.
2. Determine ways to monitor those behaviors.
3. Determine how to provide feedback to the driver.
4. Establish management and driver buy-in to the program.

This concept of operations document focuses primarily on step one, identifying unsafe behaviors, and step three, determining the best way to provide feedback to the driver. Step two, determining how best to monitor the target behaviors, will be the topic of subsequent project reports since step two focuses on issues such as system architectures and sensing technologies. However, when relevant, the concept of operations will engage in a higher level review of monitoring strategies, research regarding specific performance metrics, and discussions of the various COTS devices which may be available.

The remainder of this document is broken into four sections. Since the first step of the behavior based safety method is to identify unsafe behaviors (or behaviors that may be precursors to an increased crash rate), section 4.0 presents a literature review and general discussion on the topic of large truck crash causation. The literature on crash causation falls into two categories. First, there is a large body of literature analyzing the trends in crash data when large trucks have been involved. The most promising studies along this line of research come from the currently ongoing Large Truck Crash Causation Study being performed by the University of Michigan Transportation Research Institute and sponsored by NHTSA and FMCSA. Second, there have been many studies interviewing drivers, managers, and stakeholders in order to gauge what safety issues are paramount in the eyes of the trucking industry. These studies dictate where onboard monitoring should be focused in order to get the maximum safety benefit.

Section 5.0 of this report provides the "concept" part of the onboard monitoring "concept of operations." Specifically, a general discussion of onboard monitoring priorities and driver feedback is presented. Using a reverse Failure Modes and Effects Analysis (FMEA), possible driving behaviors (failures), which could lead to the crashes described in the crash causation literature (effects), were brainstormed and discussed as the foundational concepts for an ideal onboard driver monitoring system. Section 5.0 also attempts to frame the issues surrounding onboard monitoring driver feedback to establish a set of principles upon which recommendations regarding driver feedback should be based. In addition, several studies will be reviewed which have already posed questions pertaining to onboard monitoring feedback to industry drivers and management.

Section 6.0 of this report contains the "operations" part of the onboard monitoring "concept of operations." In this section specific recommendations are made identifying which safety related driving behaviors could be monitored, why they might be monitored, and how feedback might be provided to the driver. The first draft of these recommendations are entirely based upon the literature review. Each topic in Section 6.0 is a self-contained summary following the format listed below:

- Introduction
- Candidate Driver Behaviors for Onboard Monitoring
- Driver Feedback Recommendations
- Additional Discussion
- Cross References
- Key References

Each topic starts with an introduction which references why the topic is important. At the end of the introduction, a table spells out specifically which driver behaviors related to that topic might be candidates for onboard monitoring. A section on driver feedback recommendations discusses the various options on how driver feedback might be provided, listing the pros and cons when multiple design options are available and, where appropriate, discussing the interfaces of specific COTS devices that have been referenced on the topic.

The additional discussion subsection describes and references some of the key literature on the topic. Although performance measure options and COTS devices have been listed when available, the discussion and recommendations have been kept high level as the purpose of this document is to provide concept, not requirements or final design.

The subsection entitled "cross references" merely points the reader to other topics which might be related or utilize similar performance measures. As an example, lane position might relate to both distraction and fatigue. Finally, the key references subsection lists all of the references used in writing the section on the topic.

## 4.0 LARGE TRUCK CRASH CAUSATION

The first step in implementing the behavior-based safety method and designing an onboard driver monitoring system is to identify "unsafe" driving behaviors. Ideally, an unsafe driving behavior would be defined as any behavior that can be shown to be a precursor to increased crash risk. Thus, to understand what behaviors are unsafe, we must first understand what causes crashes involving large trucks. Unfortunately, this is no easy task.

Three methods have commonly been employed to investigate the problem of crash causation. First, panels of drivers or experts have been consulted come up with lists of safety issues in the trucking industry and "unsafe" driving behaviors. Second, many studies have mined the crash statistics associated with large trucks with some success. However, crash statistics, as currently recorded in the United States, are often vague in their details and do not necessarily reflect or contain the true causes of the crash. In response to these issues, the third approach, the Large Truck Crash Causation Study, is an in-progress study to collect an unprecedented amount of information about the drivers, vehicles, and the critical incident which lead to the crash to supplement the national database.

### 4.1 Safety Issues in the Trucking Industry

#### *4.1.1 Studies in the U.S.*

In 2003, the first in a series of TRB reports on Commercial Truck and Bus Safety was published. In this report (Knipling, Hickman, and Bergoffen, 2003) surveyed commercial motor vehicle (CMV) fleet managers and experts in motor vehicle safety on importance of 20 perceived safety problem areas in the trucking industry. The top 9 issues that were found are listed below:

1. At-risk driving behaviors (e.g., speeding, tailgating)
2. Individual high-risk drivers (all causes combined)
3. Lifestyle or general health issues (e.g., poor diet, smoking)
4. Lack of defensive driving skills (poor space management)
5. Delays associated with loading and unloading cargo
6. Driver fatigue/drowsiness
7. Aggressive driving
8. Heart Disease
9. Poor attitude, morale, emotional state

Of these 9 issues, at risk driving behaviors, defensive driving skills, fatigue, and aggressive driving are all potential candidates for an onboard monitoring system. Although aggressive driving was unable to be specifically defined, the report went on to define the following as at-risk driving behaviors (many based upon prior studies and crash data):

- Speeding
- Excessive speed on curves or in relation to weather conditions
- Improper following distatnce
- Lateral encroachment (e.g., during lane changes, due to improper mirror adjustment)
- Failure to yield at intersection
- General disobedience of the rules-of-the-road

The specifics of space management and defensive driving skills were left somewhat undefined. The general concept of space management refers to the fact that large trucks have large blind spots and limited maneuverability when reacting to actions taken by automobile drivers. In effect, space management refers to the need for truck drivers to preventively compensate for any poor decisions being made in their presence because most crashes between trucks and automobiles tend to be primarily attributed to the actions of the automobile driver.

Finally, the Knipling, Hickman, and Bergoffen (2003) reported provided a good discussion on the issue of fatigue. While it had been widely reported that fatigue was a large problem and a factor in 31 percent of single-vehicle ran-off-the-road crashes where the truck driver was killed, this particular crash type only accounts for 1 in 7 fatal truck crashes and 1 in 700 overall truck crashes. Thus, when considering truck crashes overall, the issue of fatigue is ranked as a somewhat lower priority and possibly one that is limited mostly to specific segments of the trucking industry.

While the study described above interviewed fleet managers and safety experts, two recent studies surveyed truck drivers about their safety concerns. Hanowski, et. al. (1998) conducted 11 focus groups across 5 states with a total of 82 local and short haul (L/SH) truck drivers. Across all sessions, the top five critical issues or crash causal factors as seen by drivers were as follows (ranked in order of importance to the drivers):

1. Problems caused by drivers of light vehicles
2. Stress due to time pressure
3. Inattention
4. Problems caused by roadway or dock design
5. Fatigue

The problems caused by the drivers of light vehicles, although ranked as the most important safety issue, was generally described in vague terms, such as light vehicle drivers don't show trucks enough respect. Specifically, cut-ins and backing were listed as problems with light vehicles. Interestingly, inattention was listed as one of the top 5 safety issues by drivers in this study, but there was no mention of it by management in the previous study. However, inattention, in the context of L/SH drivers, seemed to refer to the issues of multitasking while driving, such as planning your next stop or delivery or having to navigate with ineffective road signage. Similarly, fatigue, in the eyes of L/SH drivers, was used more in the context of mental fatigue as opposed to actually falling asleep at the wheel. Since L/SH drivers tend to work during daylight hours and have frequent breaks (deliveries) to interrupt their driving, fatigue is simply the result of a normal day's work, which can be exacerbated excessive heat (a lack of A/C in their vehicles) or irregular meal times.

Roetting, Huang, and McDevitt (2005) surveyed 239 long and short haul drivers specifically asking drivers to rank the importance of several critical safety behaviors. The drivers were presented with 10 behaviors and asked to select their top 3. The results are shown below in Table 4-1.

Table 4-1. Critical Safety Behaviors or Issues.

| Rank | Critical Safety Behaviors or Issues | % of Drivers Ranking in their "Top 3" |
|---|---|---|
| 1 | Looking far enough ahead and anticipating changes | 74.4 |
| 2 | Being ready to avoid the mistakes of other drivers | 55.4 |
| 3 | Turn signal use in advance of lane changes | 48.7 |
| 4 | Properly adjusting mirrors to prevent blind spots | 29.2 |
| 5 | Drowsy diving | 28.2 |
| 6 | Speeding | 17.4 |
| 7 | Seatbelt usage | 16.4 |
| 8 | Following too close | 13.3 |
| 9 | Distracting driving | 8.7 |
| 10 | Being courteous to other drivers | 8.7 |

*4.1.2 International Studies*

In New Zealand, Sullman, Meadows, and Pajo (2002) surveyed 382 truck drivers on the topic of aberrant driving behaviors falling into 3 categories:

1. Errors
2. Lapses
3. Violations

Errors included such things as failures of observation and misjudgments, e.g., braking too hard on a slippery road. Lapses were considered as failures of attention, and violations were deliberate actions such as speeding or tailgating. The questionnaire asked drivers to self-report on a scale of 0 (never) to 5 (all the time) how often they engaged in or experienced a particular behavior. Of the 3 categories, only responses to the questions on violations were predictive of increased crash risk. The most commonly reported behaviors in each category (those with a mean score above 0.5) are listed below in Table 4-2.

Table 4-2. Most common self-reported aberrant driving behaviors in New Zealand.

| Errors | Lapses | Violations | Aggressive Driving |
|---|---|---|---|
| Underestimating the speed on an oncoming vehicle while overtaking | Getting into the wrong lane at a junction | Speeding | Honking at others |
| | Having no recollection of the road you just traveled | Tailgating | Showing hostility |
| | Hitting the wrong control in the vehicle | Running a red light | Racing away from a traffic light |
| | Starting in the wrong gear | | |
| | Backing into an object | | |

In Finland, Häkkänen and Summala (2001) surveyed 251 long-haul drivers, asking them to rank 8 safety issues from the most common to the least common cause of crashes. The results are listed below in rank order from most to least common:

1. Other road users
2. Errors in truck driver perception or judgment
3. Speeding
4. Weather
5. Fatigue
6. Errors in operating the vehicle
7. Traffic environment
8. Technology faults

Unfortunately, greater detail on what was meant specifically by errors in perception or judgment or errors in operating the vehicle was not available. However, the country of Finland is somewhat unique in that every fatal crash involving large trucks has been investigated by a panel of experts to determine what factors were relevant in the cause of the crash. From 1991 to 1997, it was found that in 83 percent of the crashes involving large trucks, the truck driver was not primarily at fault. Similar to the U.S. conclusions, this evidence supports the truck drivers' view that other road users are the most common cause of crashes. In the 17 percent of crashes where the truck driver was primarily at fault, the breakdown by crash type is listed below in Table 4-3.

Table 4-3. Fatal crash type distribution when the truck driver was primarily responsible.

| Rank | Crash Type | % |
|---|---|---|
| 1 | Opposite direction or head-on collision | 50.9 |
| 2 | Same direction (overtaking, change of lane or rear-end collision) | 17.5 |
| 3 | Same direction with one vehicle turning | 10.5 |
| 4 | Intersection straight crossing path | 8.8 |
| 5 | Intersection with one vehicle turning into or across path | 5.3 |
| - | Opposite direction with one vehicle turning | 0.0 |
| - | Other | 7.0 |
| Total | | 100.0 |

The high prevalence of opposite direction head-on collisions is probably due to the fact that most of the roads traversed by trucks in Finland are two-lane highways. A different crash type distribution would probably be expected in the U.S. where multi-lane freeways are more common. In addition to determining which driver was primarily at fault, the panel of experts also made determinations about casual factors. Table 4-4 shows the percentage of crashes attributed to each causal factor. Over 50 percent of the fatal truck crashes where the truck driver was primarily at fault were attributed to errors in attention, anticipation, or estimation, and 26 percent were attributed to errors in operating the vehicle. Unfortunately, specific details were not given on these two classifications.

Table 4-4. Fatal crash casual factors when the truck driver was primarily responsible.

| Rank | Causal Factor | % |
|---|---|---|
| 1 | Error in attention, anticipation or estimation | 50.8 |
| 2 | Error in operating the vehicle | 26.3 |
| 3 | Technological faults | 7.0 |
| 4 | Driver having fallen asleep while driving | 5.3 |
| 5 | Attack of illness | 1.8 |
| 6 | Traffic environment | 1.8 |
| - | Other reasons | 7.0 |
| Total | | 100.0 |

### 4.2 U.S. Crash Statistics

There have been numerous studies employing various methods to analyze the crash statistics when large trucks are involved. In the United States, the Center for National Truck and Bus Statistics at the University of Michigan Transportation Research Institute (UMTRI) publishes a yearly Trucks Involved in Fatal Accidents Factbook, which combines data from the Fatality Analysis Reporting System (FARS) with follow-up surveys. From the latest factbook (Matteson, Blower, and Woodruffe, 2004), Table 4-5 summarizes the types of fatal crashes in which trucks are typically involved. It is interesting to note that when it comes to fatal crashes, the percentage of crashes is fairly evenly distributed among crash types. The largest single category of crash type involvement is single vehicle, either ran-off-the-road or hit and object in the road. The second largest category was rear end collisions, with the truck being the striking vehicle 38 percent of the time. Interestingly, for sideswipe and head-on collisions, the crashes typically occurred with the other vehicle striking the truck or in the truck's lane. However, for straight crossing path collisions (at intersections), the truck typically did the striking, which is probably a reflection of the well known rural crash paradigm where light vehicle drivers pull out in front of an oncoming truck having misjudged the truck's distance and speed.

Table 4-5. Trucks Involved in Fatal Crashes by Crash Type.

| Crash Type | Truck Striking (In Other Vehicle's Lane) | Other Vehicle Striking (In Truck's Lane) | Total (%) |
|---|---|---|---|
| Single Vehicle | - | - | 14.4 |
| Rear End | 5.1 | 8.2 | 13.3 |
| Sideswipe | 2.2 | 10.2 | 12.4 |
| Intersection (Straight Crossing) | 8.0 | 3.2 | 11.2 |
| Head-on | 1.1 | 9.2 | 10.3 |
| Intersection (Across Path Turn) | - | - | 9.2 |
| Backing | 0.5 | 0.1 | 0.6 |
| *Other* | | | *15.5* |
| *Unknown* | | | *13.2* |
| Total | | | 100 |

Another important study, Council, Harkey, Nabors, Khattak, and Mohamedshah (2003), examined the North Caroliana crash database from 1994 to 1997 which included 16,264 car-truck crashes. Although this database is not national, it includes all crashes, not just fatal crashes. What is most interesting to note is that while national studies of fatal truck crashes have shown that car drivers are responsible for the crash almost 70 percent of the time, truck drivers may share more of the blame when it comes to overall or non-fatal crashes. As shown in Table 4-6, Council et al. (2003) found that overall, fault was more evenly split with 48 percent of crashes being attributed to the truck driver and 40.2 percent being attributed to the car driver (with the remaining being attributed to both or neither).

Table 4-6.

| Crash Type | % Truck at Fault | % Car at Fault | Total % |
|---|---|---|---|
| Rear-end (slow) | 50.7 | 41.0 | 25.8 |
| Rear-end (turning) | 51.5 | 36.0 | 2.4 |
| Left turn (same roadway) | 45.4 | 38.6 | 8.7 |
| Left turn (crossing traffic) | 42.9 | 48.4 | 5.9 |
| Right turn (same roadway) | 43.1 | 35.5 | 4.7 |
| Right turn (crossing traffic) | 36.2 | 54.4 | 2.3 |
| Head-on | 22.5 | 71.2 | 1.4 |
| Sideswipe | 51.1 | 35.1 | 21.8 |
| Angle | 39.3 | 48.5 | 21.4 |
| Backing | 81.5 | 9.7 | 5.5 |
| Total | 48.0 | 40.2 | 100.0 |

Interestingly, most of the crash types show a fairly even split between car and truck drivers, however, there were several crash types with large disparities. Crashes that involved backing or rear-end crashes while turning were much more often the fault of the truck driver, although these two categories accounted for only 7.9 percent of the overall crashes. The largest overall category where truck drivers were most at fault was in sideswipe crashes which account for 21.8 percent. Although a detailed description was not given for this crash type, process of elimination would suggest that the authors are referring to intersection straight crossing path collisions.

### 4.3 The Large Truck Crash Causation Study

Recognizing that surveys of truck drivers and industry experts and crash statistics as currently gathered have flaws, perhaps the most definitive work which will come on the topic of truck crashes is the Large Truck Crash Causation Study (LTCCS). This joint study between FMCSA and NHTSA was currently still in progress at the time of this report. An interim report on the project status (Blower and Campbell, 2002) laid out the methodology for the study. The study was seeking to build a national sample of over 1000 fatal and serious injury crashes with supplemental information gathered to allow the coding of a critical event, a critical reason for the critical event, and other crash related factors. The critical event is defined as the action or event that put the vehicles on a collision course. The critical reason is defined as the immediate reason for the critical event.

The distribution of critical events for two-vehicle crashes is detailed in Table 4-7 based on presentation of the LTCCS interim results (Craft and Blower, 2004). At the time of this report, the LTCCS had only examined 589 raw crash samples and only 287 of those crashes were two-vehicle crashes between a car and a truck. The largest 3 categories of critical events (almost 80 percent of the crashes) included driving out of the lane, turning at or crossing intersections, and rear-end crashes.

Table 4-7. LTCCS critical events broken by vehicle exhibiting the critical event.

| Critical Event (for two-vehicle crashes) | Truck (%) | Other Vehicle (%) | Total Crashes (%) |
|---|---|---|---|
| Vehicle | 1 | 1 | 1 |
| Roadway or environment | 0 | 3 | 2 |
| Loss of control (driving too fast) | 3 | 10 | 8 |
| Driving over the lane or off the road (including head-on and lane change) | 35 | 29 | 30 |
| Turning at or crossing an intersection | 27 | 28 | 28 |
| Same lane (rear-end) | 28 | 27 | 26 |
| Other | 8 | 3 | 5 |
| Total | 100 | 100 | 100 |

Although the results in Table 4-7 somewhat resemble past studies detailing crash type by fault, the power of the LTCCS is in the fact that it goes beyond just crash type. As shown in Table 4-8, the critical reasons for the critical events are shown for the same two-vehicle crashes described in Table 4-7. The largest critical reason found for two-vehicle crashes was inattention, followed closely be poor decisions or misjudgment. These two factors alone account for over 80 percent of two-vehicle crashes caused by truck drivers.

Table 4-8. The critical reason for two-vehicle crashes with trucks.

| Critical Reason | Truck (%) | Other Vehicle (%) | Total (%) |
|---|---|---|---|
| Vehicle (typically brake failure) | 6 | 4 | 5 |
| Environment | 0 | 6 | 4 |
| Driver nonperformance (sleep or sickness) | 3 | 11 | 9 |
| Driver recognition (inattention or external distractions) | 46 | 34 | 38 |
| Driver decisions (misjudgments) | 36 | 20 | 25 |
| Driver performance (poor control) | 5 | 9 | 8 |
| Driver unknown errors | 3 | 13 | 10 |
| Other/unknown | 1 | 3 | 2 |
| Total | 100 | 100 | 100 |

Inattention or distraction was also found frequently as a related factor in the crash. Internal distractions were found to be related to almost 17 percent of the two-vehicle crashes, and external distractions were found to be related to almost 8 percent of the two-vehicle crashes. Poor surveillance, driving too fast, and making false assumptions were each found to be related to about 10 percent of the crashes, but following too close was only a factor in 4 percent of the crashes. By far, the largest related factor was prescription or over-the-counter medications which were a factor in almost 34 percent of the two-vehicle crashes.

The results described in the tables above for the critical reasons of two-vehicle truck crashes hold fairly true when looking at all truck crashes. For all truck crashes, 53 percent of the time the critical reason was not associated with the truck or truck driver. Nearly 31 percent of the crashes could be attributed to driver inattention, distraction, misjudgments, or poor decisions. Only 4 percent of crashes could be attributed sleep or sickness, and only 4 percent of crashes could be attributed to poor vehicle control. Finally, a full 5 percent of crashes could be attributed to vehicle failures (typically brakes), meaning that the top 5 critical reasons accounted for almost 97 percent of crashes.

### 4.4 Crash Causation Conclusions

When surveyed, the industry experts, truck drivers, fleet managers, and safety experts, all agree on several points. First, aggressive or risky truck driver behaviors, such as speeding or tailgating, consistently rank high among industry concerns. Second, inattention and distraction are major problems which need to be addressed. Third, a primary function of the truck driver is to anticipate and proactively react to the unexpected, dangerous, and poor decisions made by the drivers light vehicles. The crash statistics and crash causation studies generally support these claims citing that over half the crashes are not primarily the fault of the truck driver, but rather the fault of the car driver. However, when the crashes can be attributed to the truck or truck driver, inattention, distraction, misjudgments, and poor decisions were the primary reasons.

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# 5.0 ONBOARD DRIVER MONITORING CONCEPTS

## 5.1 Driver Monitoring Priorities

In system engineering terms, the crash causation literature detailed in Section 4.0 is akin to a Root Cause Analysis (RCA). It provides background on how frequently truck crashes happen and why. The challenge at hand is to organize, prioritize, and translate the crash causation research into a concept of operations for an onboard driver monitoring system. Although there are an infinite number of ways this problem could be viewed and organized, the primary goal of onboard driver monitoring is risk management. One tool used widely in the system engineering approach for risk management is Failure Modes and Effects Analysis (FMEA). This tool is simply a formal process to proactively identify and correct potential product failures by examining each component, how that component might fail, and what effect that failure might have on the overall system.

However, if we consider each specific driver behavior as a system component with the potential for failure, the task at hand is actually the reverse of the FMEA intention. In this case, the failure effects and frequencies, i.e., crash types, are known, and thus, priority should come from the frequency and severity of the specific crash types. Additionally, the most likely potential failure modes or root causes of those crashes are also known (distraction, poor decisions, etc.). Continuing to work backwards through the FMEA method, what is unknown is what specific driver behaviors (or system components) are predictive of each failure mode and, consequently, should be monitored.

Based on the findings of the LTCCS, three general categories of critical events leading to crashes could be considered high priority: (1) driving over the lane or off the road, (2) turning at or crossing an intersection, and (3) rear-end collisions. The most common reasons for the critical event were driver errors in recognitions (due to inattention or distraction) and errors in decisions (misjudgments). Most studies agree that fatigue, or falling asleep at the wheel, is a much lower priority and only a primary factor in maybe 3 percent of truck caused crashes.

### *5.1.1 Driving Over the Lane or Off the Road*

The LTCCS suggested that nearly 35 percent of truck crashes resulted from driving out of the lane or off the road. Additionally, 3 percent of truck crashes resulted from losing control of the vehicle. Although it was the largest single category of critical events found in the LTCCS, the category itself combines several crash types. Crashes which result from a lane departure could include single vehicle run-off-the-road, head-on, or lane change and merging crashes. Table 5-1 attempts to break down each crash type and primary mode of failure into possible behavioral failures on the part of the truck driver.

Table 5-1. Possible behavioral failures for crashes resulting from lane departure.

| | Effect (Crash Scenario) | Mode (Critical Reason) | Failure (Possible Behavior Failures) |
|---|---|---|---|
| 1 | Single vehicle runs off the road or two vehicle head-on collision | Recognition | • Driver takes eyes off the road (distraction)<br>• Fatigue/falling asleep |
| | | Decision | • Driving too fast for weather<br>• Overdriving headlights at night<br>• Curve over speed |
| 2 | Overtaking | Recognition | - |
| | | Decision | • Misjudging the speed of an oncoming vehicle<br>• Misjudging the amount of safe passing roadway available and the time it will take to complete the maneuver |
| 3 | Lane change/merge | Recognition | • Failure to check mirrors<br>• Failure to properly adjust mirrors |
| | | Decision | • Failure to use turn signals |

Of the potential behavioral failures, speed is fairly easy to measure. However, absolute speed alone is not the issue. The issue is speed relative to roadway conditions, which could be roadway design such as in the case of curve over speed or a combination of roadway design and weather conditions. Other driver decisions, such as misjudgments of oncoming vehicle speed and distance, are far more difficult to monitor as they would involve the need to know or measure the speeds and distances of the surrounding vehicles.

Distraction and fatigue (or falling asleep) are also somewhat difficult to measure, but there are options and COTS devices available. The most direct measure for both distraction and sleep is monitoring eye scan behavior; however, there may also be the possibility of using surrogate measures such as lane keeping performance.

### *5.1.2 Turning at or Crossing an Intersection*

Another large category of critical events suggested by the LTCCS was crashes resulting from turning at or crossing an intersection, approximately 27 percent of the crashes caused by the truck or truck driver. Again, although this category comprises a large amount of crashes, there are numerous permutations of intersection crashes, including making a left turn across the path of an oncoming vehicle, straight crossing path, left turn across the path of lateral traffic, and right turn into the path of lateral traffic. Furthermore, intersection crashes can be complicated by control method, uncontrolled, stop sign, or traffic signal. Table 5-2 details the possible driving behavior failures which may result in an intersection crash.

Table 5-2. Possible behavioral failures for intersection crashes.

| Effect<br>(Crash Scenario) | Mode<br>(Critical Reason) | Failure<br>(Possible Behavior Failures) |
|---|---|---|
| Intersection crashes | Recognition | • Driver takes eyes off the road<br>• Driver does not see intersection control (stop sign or stoplight)<br>• Driver does not check lateral traffic in both directions before crossing<br>• Driver does not check or see oncoming traffic before turning |
| | Decisions | • Driver misjudges oncoming vehicle speed or distance<br>• Driver misjudges lateral vehicle speed or distance<br>• Driver does not stop for intersection control (stop sign or stop light)<br>• Driver does not properly yield to a vehicle with the right-of-way |

Intersection crashes often result from an extremely complicated set of causal factors. The main difficulty in monitoring intersection behavior is that many of the crashes result from misjudgments or poor decisions. In order to detect and monitor these decisions, one would need to know the speeds and positions of all the vehicles approaching the intersection. Although this may be possible one day with the advent of intelligent intersections, vehicle-to-infrastructure, and vehicle-to-vehicle communications, these technologies are still a ways off. However, what may be possible in the present or near future is monitoring whether the driver intentionally or unintentionally disobeys traffic controls, such as stop signs or stop lights.

### *5.1.3 Rear-End Collisions*

The final major category of critical events suggested by the LTCCS was same-lane crashes or rear-end collisions which accounted for approximately 28 percent of the crashes caused by the truck or truck driver. Table 5-3 details the possible driving behavior failures that may result in a rear-end collision. Unlike intersection crashes, many of these behaviors are prime candidates for monitoring both directly and indirectly with current sensor technology.

Table 5-3. Possible behavioral failures in rear-end crashes.

| Effect (Crash Scenario) | Mode (Critical Reason) | Failure (Possible Behavior Failures) |
|---|---|---|
| Rear-end collision | Recognition | • Driver takes eyes off the road (distraction)<br>• Fatigue/falling asleep<br>• Failure to anticipate changes ahead in traffic (stopped traffic or turning vehicles)<br>• Failure to predict and react to vehicle cut-ins |
| | Decision | • Following too close<br>• Following too close for weather<br>• Speeding compared to traffic flow (aggressive driving) |

### *5.1.4 Fatigue, Sleep, and Other Lower Priority Issues*

The issues of fatigue and drowsy driving (falling asleep while driving) are interesting. The LTCCS found only about 3 percent of crashes to be primarily caused by drivers actually falling asleep at the wheel; however fatigue was listed as a related factor nearly 5 percent of the time. It should be noted that there is a distinction to be made when talking about fatigue and talking about drowsy driving or falling sleep at the wheel. Fatigue is a condition that occurs long before drowsy driving or actually. Fatigue can mimic distraction which was also mentioned as a possible cause of many crash types, and the symptoms common to both include reduced scanning patterns and scanning frequency, slowed reactions, and making poorer decisions.

While monitoring whether or not the driver is actually falling asleep at the wheel is probably not the highest priority based on the crash causation studies, it has been reported as a major safety issue in the trucking industry, especially for long-haul drivers. An ideal onboard driver monitoring system may provide drowsy driver monitoring as an option to be used with long-haul drivers. Additionally, one driver monitoring countermeasure already mandated by state and federal regulatory agencies is the logging of driver hours of service. Since this logging is already required of drivers, any onboard monitoring system should automatically handle this task. As discussed earlier, any benefit of the system perceived by the driver, such as cutting down on paperwork, helps with overall system acceptance.

Vehicle failures, typically brakes, were responsible for 5 to 6 percent of crashes according to the LTCCS. Consideration might be given to monitoring driver behaviors that can lead to or cause vehicle failures, such as riding the brakes when descending prolonged steep hills. Finally, although not specifically the cause of crashes, seat belt usage is essential to injury reduction in a crash, and it has been reported as a concern of the trucking industry. Interestingly, although it may seem commonplace, the monitoring and feedback of seat belt usage already exists and has, in fact, been mandated as part of vehicle design.

### 5.2 Driver Feedback Concepts

The end goal of onboard driver monitoring is to be able to provide the driver with feedback that will have a positive influence by promoting safe behaviors and discouraging unsafe behaviors. As part of the Roetting, Huang, and McDevitt (2003) study, truck drivers were surveyed on questions of how they would like to receive feedback from an onboard driver monitoring system. Unsurprisingly, they found little consensus over how feedback on driving performance should be given. Their results showed that when asked the generic question of how to provide feedback, 47 percent opted for via a dashboard device, 37 percent opted for post-driving feedback, and 30 percent opted for some sort of voice-auditory system. When post-driving feedback suggested as an option, drivers generally selected a time summary interval between once a week and once a month, as opposed to longer or shorter time intervals. One thing that the drivers did agree on, was that any technology providing feedback should not interfere with the driving task and should not be a distraction.

Quite simply, the answer to the question of feedback varies depending on the specific feedback being provided. In order to start deciding what feedback should be given in what way, we must first establish how the role of onboard driver monitoring feedback fits into the overall scheme of driver assistance. Figure 5-1 was first published in a report by NHTSA (1992) as a means of describing the relationship between urgency (x-axis) the intensity of intervention required (y-axis). Since the first appearance of this graph, two categories have been added by researchers at California PATH: situational awareness and onboard monitoring feedback.

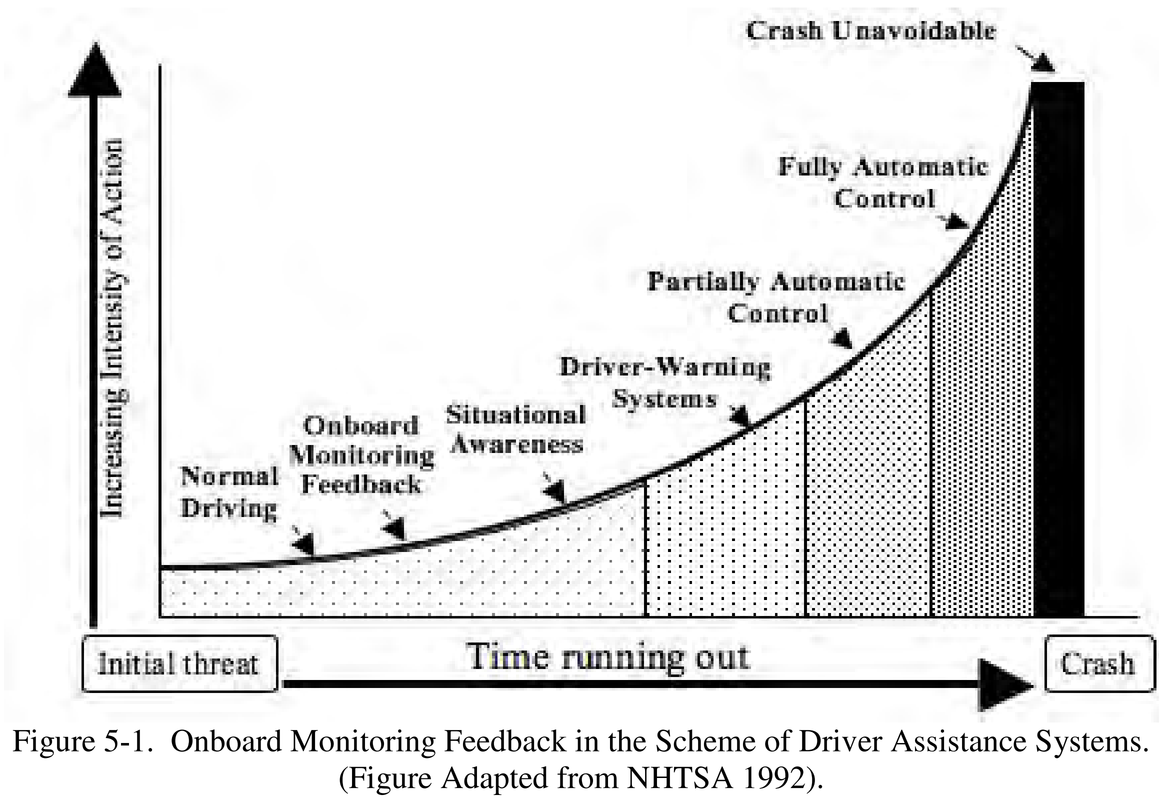


Figure 5-1. Onboard Monitoring Feedback in the Scheme of Driver Assistance Systems. (Figure Adapted from NHTSA 1992).

The important distinction which is illustrated by Figure 5-1 is that onboard monitoring feedback is not a warning system. A warning system, in the classical sense, provides the driver with information that a specific, urgent threat exists, and immediate action must be taken to avoid that threat. The most prominent examples in the automotive realm are forward and side collision warning system. Designing a warning system that will be accepted by drivers typically considers issues such as reaction time and false alarms.

Situational awareness systems are generally one step removed in urgency with the intention of providing the driver with supplemental information, upon which better informed decisions can be made. The best example of a situational awareness system is a side object detection system. When an object in the driver's blind spot is detected, the information is transferred or fed back to the driver. The difference between situational awareness and warning is that an immediate threat does not need to be present. In designing a situational awareness system, timing issues are generally considered, but timing and false alarms are much less critical.

It is our assertion that onboard driver behavior monitoring feedback is even one more step removed in urgency from situational awareness. Behavior monitoring feedback merely attempts to convey that the driver is currently engaging in what might be considered an unsafe behavior. A prime example of this is feedback provided by most vehicles on driver seat belt usage. This feedback is not a warning, as there is no immediate threat, but it does indicate that the behavior of not wearing your seatbelt is dangerous. In the design of behavioral feedback, the issue of timing in relationship to crash is not critical. False alarms are also less critical, unless the feedback is overly distracting.

Perhaps the first and largest question regarding onboard driver monitoring feedback is the question of whether the feedback should be immediate (real-time and somehow provided in the vehicle) or can be delayed (allowing post-processing). The general guiding principle on this issue comes down to whether or not the unsafe behavior is persistent and correctable. Nonuse of the seatbelt is persistent and correctable by the driver, and thus, immediate feedback is a good option. Following too close is also a good candidate for immediate feedback, as it is a persistent state correctable by the driver.

Other monitoring parameters don't lend themselves well to immediate feedback. As an example, if the driver just performed a hard braking because he was distracted and didn't see the car in front of him start braking, the condition was not persistent or correctable. The event is over and providing the driver with immediate feedback that he just performed a hard braking event is pointless. In this particular example, feedback would better serve the driver by summarizing how many hard braking events he found himself in during the past week or month. In a case where a single event does not necessarily indicate a problem but frequent events may be indicative of a larger correctable problem, then delayed feedback would be more appropriate.

Another issue which needs to be considered is whether the feedback provided should be positive or negative. In the case of immediate or in-vehicle feedback, positive feedback would generally be avoided. As a general principle, one does not add in-vehicle displays unless necessary for fear of introducing unnecessary distraction. Thus, for the case of following too close, the preferred feedback would only occur when the driver was following too close for an extended period of time. However, when giving delayed feedback, several of the studies mentioned earlier reported that drivers wanted to hear the positive about their driving and not just the negative.

The final topic of onboard driver monitoring feedback is how to provide immediate in-vehicle feedback, specifically, through which modality: auditory or visual. Typically, auditory feedback is used in situations where an immediate response is needed, and the driver's attention may or may not be focused on the feedback device (or the road for that matter). The problem with auditory feedback is that it quickly becomes annoying and even distracting when overused or used in the wrong situation because drivers have no means to avoid it. Thus, following the advice of the 30 percent of drivers who responded that they would prefer feedback through some auditory-voice type system would not be recommended. There are cases, however, where auditory warnings have been used for non-critical situations, e.g., the seat belt monitoring system. In the case of the seat belt monitoring system, the annoyance and distraction factor of the auditory warning was intentional with the hope that it would persuade drivers to comply at the start of their trip. Of course, the disadvantage of this strategy and too much distraction and annoyance is risk of the driver attempting to disable the system entirely.

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# 6.0 ONBOARD DRIVER MONITORING OPERATIONS

## 6.1 Monitoring Behaviors Related to Vehicle Speed

*Introduction:*

Both Tables 5-1 and 5-3, describing lane departure and rear-end crashes, list several ways that vehicle speed could be a potential driving behavior failure contributing to a crash scenario. Speeding, under the banner of aggressive driving, was also listed as one of the top concerns among industry experts (Knipling, Hickman, and Bergoffen, 2003) and by long and short haul truck drivers by (Roetting, Haung, and McDevitt, 2005).

| Candidate Driver Behaviors for Onboard Monitoring |
|---|
| 1. Vehicle speed relative to roadway speed limit |
| 2. Vehicle speed relative to safe curve speed |
| 3. Vehicle speed relative to roadway (weather) conditions |
| 4. Vehicle speed relative to night visibility (headlight sight distance) |
| 5. Vehicle speed relative to traffic flow |

*Driver Feedback Recommendations:*

| Recommended Driver Feedback Designs |
|---|
| 1. Delayed or off-line feedback with summary statistics |
| 2. Real-time feedback in the form of a series of speed warning or status lights |
| 3. Engine speed limiters |

Three driver feedback options have been presented both in order of complexity and in order of the aggressiveness of the intervention. An vehicle speed monitoring system could be effectively built around any or all of these driver feedback schemes. Realistically, the driver already receives feedback about vehicle speed from the speedometer and feedback about the speed limit and recommended curve speeds from signs on the roadside. For these reasons, off-line or delayed feedback could be justified.

As long as the information is available, an argument could also be made to provide the driver with some indication or comparison of current and recommended speed, so long as it's presented in a way that does not distract the driver. While perhaps the best system utilizing this method of feedback might include concepts such as a reconfigurable speedometer, simpler instantiations could include a series of speed warning or status lights which illuminate when the recommended speed has been exceeded. At least in the case of curve over speed, system design consideration must be given to the overall goal of safety. If the information is available to monitor curve speed compliance, should it also be coupled with a curve over speed warning system to aid the driver?

Conceivably, the strictest and most aggressive form of driver speed monitoring and feedback would be to electronically disallow the vehicle from traveling above the recommended speed. While systems exist currently to simply limit the overall top speed of a vehicle, there are many more human factors issues with the implementation of a dynamic speed limiting system.

Although this feedback method may eventually be an option, it would likely be coupled with visual indicators, and the number of implementation questions for which there is currently little or no research would make this option challenging.

One alternative that has not been recommended based on the current research is the use of force feedback on the accelerator pedal to influence driver speed selection. While Várhelyi, Hjälmdahl, Hydén, and Draskóczy (2004) have reported some success in Sweden using accelerator pedal feedback for speed limit compliance, other studies currently being conducted on the topic of curve over speed have preliminarily reported limited effectiveness and sometimes even adverse effects when using accelerator pedal feedback. More conclusive research on this topic will likely be released in the next few years and should be carefully reviewed before recommending accelerator pedal feedback as an option.

*Additional Discussion:*

In 1998 the Transportation Research Board published *Special Report 254*, a review of current knowledge and literature on the topic of speed and safety. This report, along with a more recent paper from the Netherlands (Aarts and van Shagen, 2006), summarized that although the evidence is not conclusive, there is evidence that both increasing speed and increasing speed disparity can be associated with crash involvement and crash severity for certain crash types. As an example, increased speed can be associated with increases in single-vehicle or ran-off-the-road types of crashes. At higher speeds, deviations from the average traffic speed has been shown to increase crash probability. In all cases, crash and injury severity rises sharply with increased speed, which simply reflects the laws of physics which state the energy of an impact will be proportional to the square of the speed.

*Cross References:*

*See Section 6.2 (Following Distance)* - Monitoring vehicle speed relative to traffic flow is related to rear-end collisions and may also be related to following distance.

*Key References:*

Aarts, L. and van Shagen, I. (2006). Driving Speed and the Risk of Road Crashes: A Review. *Accident Analysis and Prevention. 38*, 315-224.

Knipling, R., Hickman, J., and Bergoffen, G. (2003). *Commercial Truck and Bus Safety Synthesis Program: Synthesis 1 - Effective Commercial Truck and Bus Safety Management Techniques.* Washington D.C.: Transportation Research Board.

Roetting, M., Huang, Y., McDevitt, J.R., Melton, D., Smith, G.S. (2005). Feedback by technology: Attitudes and opinions of truck drivers. *Transportation Research Part F. 8*, 277-297.

Transportation Research Board (1998). *Managing Speed: Review of Current Practice for Setting and Enforcing Speed Limits* (Special Report 254). Washington D.C.: National Research Council.

Várhelyi, A., Hjälmdahl, M., Hydén, C., and Draskóczy, M. (2004). Effects of an active accelerator pedal on driver behaviour and traffic safety after long-term use in urban areas. *Accident Analysis and Prevention. 36*, 729-737.

## 6.2 Monitoring Following Distance

*Introduction:*

The large truck crash causation study (LTCCS) found that rear-end collisions accounted for approximately 28 percent of the crashes caused by truck drivers. Table 5-3 lists following too close as a potential driving behavior failure which could contribute to a rear-end crash. Following too close was also listed under the banner of aggressive driving which was one of the top concerns among industry experts (Knipling, Hickman, and Bergoffen, 2003) and by long and short haul truck drivers by (Roetting, Haung, and McDevitt, 2005).

| Candidate Driver Behaviors for Onboard Monitoring |
|---|
| 1. Following too close for travel speed and trailer loading |
| 2. Following too close for weather conditions |

*Driver Feedback Recommendations:*

| Recommended Driver Feedback Designs |
|---|
| 1. Delayed or off-line feedback with summary statistics |
| 2. Real-time feedback in the form of a warning/status light |
| 3. Forward collision warning system |

Effective feedback for following distance could be provided in the form of delayed summary feedback, a real-time following too close warning/status light, or a fully functional forward collision warning system. Real-time feedback on this parameter is highly recommended as Shinar and Schechtman (2001) have effectively shown that providing real-time following distance feedback to drivers has a lasting improvement on inter-vehicular distance.

System design consideration must also be given to the overall goal of safety. If the information is available to monitor following distance, should it also be coupled with a fully functional forward collision warning system to aid the driver, especially since it was found in earlier research that the more tangible benefits that the system could provide, the more likely that drivers would accept the system.

Additionally, there will likely be an issue with handling vehicle cut-ins, which are a common problem around heavy trucks. Specifically, drivers will likely be unhappy if their feedback penalizes them for following too close when an event was not considered their fault.

*Additional Discussion:*

Tables 6-1 compares the stopping distances required by both cars and trucks for various initial speeds. The stopping distances are based on typical deceleration rates as reported by Radlinski (1987) for a variety of light and heavy vehicles; however, these numbers are on the extreme side as maximum vehicle braking capabilities often exceed the limit drivers are willing to push them. From the required stopping distances, a safe following distance can be computed by subtracting a typical car's stopping distance from the truck's stopping distance and adding buffers for air brake lag and driver reaction time. Air brakes typically take a half-second to build up pressure before braking can start; however, some models of truck may take up to a full second. The typical value reported for driver perception-response time is 1.5 seconds which was the 95 percentile response time found in the CAMP project (Kiefer, et al., 1999) for a reasonably attentive driver.

Table 6-1. Safe following distance by speed for cars.

| Speed (mph) | Speed (m/s) | Car Stopping Distance (m) | Truck Stopping Distance (m) | | Safe Following Distance (m) | Seconds |
|---|---|---|---|---|---|---|
| | | | Min (m) | Max (m) | | |
| 10 | 4.5 | 1.5 | 2.2 | 2.7 | 10.1 | 2.3 |
| 20 | 8.9 | 6.1 | 8.7 | 10.8 | 22.6 | 2.5 |
| 30 | 13.4 | 13.6 | 19.5 | 24.3 | 37.5 | 2.8 |
| 40 | 17.9 | 24.2 | 34.8 | 43.2 | 54.7 | 3.1 |
| 50 | 22.4 | 37.8 | 54.3 | 67.5 | 74.4 | 3.3 |
| 60 | 26.8 | 54.5 | 78.2 | 97.2 | 96.4 | 3.6 |
| 70 | 31.3 | 74.2 | 106.4 | 132.3 | 120.7 | 3.9 |

Factors such as trailer loading and weather conditions may also be important when determining the safe following distance; however, these factors were not included in this Table 6-1. Additionally, some fine tuning will likely be necessary to adjust safe following distances based on typical driver preferences and to make sure that opportunity for even more hazardous situations aren't created (such as opportunity for vehicle cut-ins).

Eaton (http://www.vorad.com/) is one of the leading COTS manufacturers of commercial collision warning systems, and they currently manufacture the VORAD radar-based Forward Collision Warning System specifically designed for trucks. Delphi also has a COTS forward collision warning system called Forewarn (http://delphi.com/manufacturers/cv/safesecure/).

<u>*Cross References:*</u>

*See Section 6.1 (Vehicle Speed)* - Following distance is related to rear-end collisions and another metric which may also be related is vehicle speed relative to traffic flow.

*See Section 6.3 (Attention)* - Safe following distances are based on the attentive driver. Although rear-end collisions were one of the three major crash scenarios found in the LTCCS, intentionally following too close was only a factor in maybe 4 percent of crashes, and inattention was to blame far more often.

*See Section 6.4 (Hard Braking Incidents)* - Same as above.

<u>*Key References:*</u>

Kiefer, R, LeBlanc, D., Palmer, M., Salinger, J, Deering, R., & Shulman, M. (1999). *Development and Validation of Functional Definitions and Evaluation Procedures for Collision Warning/Avoidance Systems* (NHTSA Technical Report DOT HS 808 964). Crash Avoidance Metrics Partnership (CAMP), Farmington Hills, MI.

Radlinski, R. (1987). Braking Performance of Heavy U.S. Vehicles (SAE Paper No. 870492). *SAE Transactions*. Warrendale, PA: SAE International.

Shinar, D. and Schechtman, E. (2001). Headway feedback improves inter-vehicular distance: a field study. *Human Factors. 44*, 474-481.

### 6.3 Monitoring Attention

*Introduction:*

The Large Truck Crash Causation Study (LTCCS) found that nearly 46 percent of the two-vehicle crashes caused by trucks were primarily attributed to inattention or distractions (See Table 4-8). Overall, inattention or distraction was an associated or related factor in over 25 percent of crashes. In Tables 5-1, 5-2, and 5-3, distraction was listed as a potential behavioral failure for all of the major types of truck crashes including single vehicle ran-off-the road crashes, head-on collisions, intersection crashes, and rear-end collisions.

| Candidate Driver Behaviors for Onboard Monitoring |
|---|
| 1. Driver eyes-off-the-road time |
| 2. Driver eye scanning patterns |
| 3. Surrogate measures (see hard braking incidents and lane position) |

*Driver Feedback Recommendations:*

| Recommended Driver Feedback Designs |
|---|
| 1. Delayed or off-line feedback with summary statistics |
| 2. Real-time feedback of eyes-off-the-road time and traveled distance |
| 3. Supplement to a collision warning system |

Feedback for driver attention monitoring could be provided in the form of delayed summary feedback or possibly through a real-time display. Inspiration for a real-time eyes-off-the-road feedback device might come from the interface developed by Attention Technologies for their drowsy driver detection system (Ayoob, Grace, and Steinfeld, 2003). In this system eyes closed time along with distance traveled in that time is fed back to the driver.

Recent news releases from Japan have described a driver attention monitoring system currently being researched by Toyota. The system recognizes facial orientation to establish probable eyes-off-the-road events to supplement collision and pre-crash warning systems. If the driver is found to be looking away from the road, the forward collision warning could be given sooner and stronger in an attempt to get the driver back to being focused on the road ahead. Thus, in the pursuit of overall system safety, if the information is available from monitoring eyes-off-the-road time and following distance, should the monitoring feedback also be coupled with collision warning systems to aid the driver?

*Additional Discussion:*

Two direct measures of driver attention (or inattention) have been proposed and discussed in the literature: (1) eyes-off-the-road time and (2) changes in the driver's scanning patterns. Eyes-off-the-road time has generally been referenced in the context of the design of in-vehicle devices, specifically, navigation systems. Green (1998) summarizes links that have been found in the literature between eyes-off-the-road time (glance duration and frequency) and lane departures. More recently, Victor, Harbluk, and Engström (2005) have shown that changes in eye scanning patterns may also indicate distraction or inattention. Specifically, when attention becomes divided between two tasks, such as driving and an in-vehicle task, the driver's scanning pattern of the road ahead becomes more tunneled.

While direct measures of attention tend to focus on the driver's visual attention, indirect or surrogate measures of attention might include looking at the outcome or resultant. Potential indications that a driver is or has been distracted might include hard braking incidents or excessive weaving (poor lane position control).

*Cross References:*

*See Section 6.2 (Following Distance)* - Rear-end collisions are a typical byproduct of an attention failure, and the typical countermeasure is a forward collision warning system as discussed in Section 6.2.

*See Section 6.4 (Hard Braking Incidents)* - Hard braking incidents may provide a surrogate measure for monitoring attention.

*See Section 6.5 (Lane Position)* - Ran-off-the-road crashes are a typical byproduct of an attention failure, and the typical countermeasure is a lane departure warning system as discussed in section 6.5. Lane position may provide a possible surrogate measure for monitoring attention.

*Key References:*


Ayoob, E., Grace, R., and Steinfeld, A. (2003). A user-centered drowsy-driver detection and warning system. *Proceedings of the 2003 conference on Designing for user experiences.* New York, NY: Associations for Computing Machinery (ACM).

Green, P. (1998). *Visual and Task Demands of Driver Information Systems* (Technical Report UMTRI-98-16). Ann Arbor, MI: The University of Michigan Transportation Research Institute.

Victor, T., Harbluk, J., and Engström, J. (2005). Sensitivity of eye-movement measures to in-vehicle task difficulty. *Transportation Research Part F. 8*: 167-190.

## 6.4 Monitoring Hard Braking Events

*Introduction:*

Rear-end crashes (Table 5-3) can potentially result from many behavioral failures such as distraction, falling asleep, failures to anticipate changes in traffic, and failures to react to vehicle cut-ins. Since many of these behaviors are difficult to monitor directly, one potential solution is to monitor, record, and investigate near misses which can be defined as hard braking events.

| Candidate Driver Behaviors for Onboard Monitoring |
|---|
| 1. The frequency of hard braking events<br>2. The engineering details and forward looking video surrounding the event |

*Driver Feedback Recommendations:*

| Recommended Driver Feedback Designs |
|---|
| 1. Delayed or off-line feedback with summary statistics |

Feedback for near misses or hard braking events is best provided off-line with summary statistics. A real-time feedback system for these events would not be recommended since the driver would already be aware of the event, and the event would be completed by the time the system could react. Even if the system could detect and react during a hard braking event, it would not be recommended as the driver's attention should be focused on controlling the vehicle at that point, not on receiving feedback. Useful feedback on hard braking events comes from reviewing event frequency over time. While the driver may be aware of an individual braking event, the driver may not realize just how many situations he or she gets into that require hard braking during a specific time period or how that compares to other drivers.

*Additional Discussion:*

The XATA, the Accident Prevention Plus, and the DriveCAM onboard monitoring COTS systems record hard braking events. The DriveCAM system also records audio and video both before and after the incident.

*Cross References:*

*See Section 6.2 (Following Distance)* - Hard braking incidents may be related to rear-end collisions which are also related to following distance.

*See Section 6.3 (Attention)* - Hard braking incidents may provide a surrogate measure for attention.

*See Section 6.7 (Incidents)* - Hard braking incidents are just one of many incidents that might be monitored and recorded.

*Key References:*

None.

## 6.5 Monitoring Lane Position

As described in Table 5-1, lane departures was one of the three major critical reasons for truck crashes as identified in the Large Truck Crash Causation Study (LTCCS) which can result in ran-off-the road crashes, head-on collisions, and lane change or merge crashes. Although poor vehicle control only accounted for about 5 percent of truck caused crashes (Table 4-8), lane position might also provide a surrogate measure of driver inattention, which can also lead to crashes.

*Introduction:*

| Candidate Driver Behaviors for Onboard Monitoring |
|---|
| 1. Lane position<br>2. Steering inputs |

*Driver Feedback Recommendations:*

| Recommended Driver Feedback Designs |
|---|
| 1. Delayed or off-line feedback with summary statistics<br>2. A lane departure warning system |

Feedback on lane position would best be provided off-line with summary statistics or real-time through a lane departure warning system. Most measures of lane keeping performance are either normalized over time or for the express purpose of predicting a lane departure. Providing lane keeping performance feedback after a lane departure would be similar to providing feedback after a hard braking event. The driver already knows that an event has occurred and the feedback could potentially be distracting. What the driver may not realize is how many lane departure events he becomes involved in and how this compares to other drivers.

Real-time feedback would best be provided through a predictive lane departure warning system. Iteris (http://www.iteris.com/) is one of the leading COTS manufacturers of commercial truck lane departure warning systems. Delphi also has the Forewarn Lane Departure Warning system (http://delphi.com/manufacturers/cv/safesecure/).

*Additional Discussion:*

Three direct measures of lane keeping performance have generally been proposed and discussed in the literature: (1) the number of lane departures per VMT, (2) the standard deviation of lane position (over some time window), and (3) time-to-line crossing (TLC). The standard deviation or variance of lane position has generally been reported in the literature as a measure of lane keeping performance. However, it is generally used to compare one condition to another, and absolutes using this measure have never been defined. Green, et al. (2003) provides a good summary of how the standard deviation of lane position has been used in the past.

Time-to-line crossing was first suggested by Godthelp, Milgram, Blaauw (1984), and more recently in a paper comparing the merits of various calculation methods by van Winsum, Brookhuis, and de Waard (2000).

Two indirect measures of lane keeping performance have been proposed and discussed in the literature: (1) steering wheel reversals and (2) steering entropy ($H_p$). Steering wheel reversals had been proposed as a measure of workload, but it was not found to be a very sensitive measure. Steering entropy is a promising measure that has been recently proposed to quantify drivers' efforts to maintain lateral safety margins (Boer, 2001, and Boer, et al., 2005). Steering entropy was originally developed as a measure that might be used quantify reduced or diverted attention or changes in the driver's workload, and has recently also been proposed as a measure of fatigue (Paul, Boyle, Boer, Tippin, and Rizzo, 2005).

*Cross References:*

*See Section 6.3 (Attention)* - Lane position may provide a possible surrogate measure for monitoring attention.

*See Section 6.6 (Lane Changes)* - While Section 6.5 covers unintentional lane departures, Section 6.6 covers intentional lane departures.

*Key References:*

Boer, E. (2001). Behavioral Entropy as a Measure of Driving Performance. *Proceedings of the First International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design.* Iowa City, IA: The University of Iowa. [Available Online at http://ppc.uiowa.edu/driving-assessment/]

Boer, E., Rakauskas, M., Ward, N., and Goodrich, M. (2005). Steering Entropy Revisited. *Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design.* Iowa City, IA: The University of Iowa. [Available Online at http://ppc.uiowa.edu/driving-assessment/]

Godthelp, J., Milgram, J., Blaauw, G. (1984). The development of a time-related measure to describe driving strategy. *Human Factors. 26*, 257–268.

Green, P., Cullinane, B., Zylstra, B., and Smith, D. (2003). *Typical Values for Driving Performance with Emphasis on the Standard Deviation of Lane Position: A Summary of Literature* (Technical Report UMTRI-2003-42). Ann Arbor, MI: The University of Michigan Transportation Research Institute.

Paul, A., Boyle, L., Boer, E., Tippin, J., and Rizzo, M. (2005). Steering Entropy Changes as a Function of Microsleeps. *Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design.* Iowa City, IA: The University of Iowa. [Available Online at http://ppc.uiowa.edu/driving-assessment/]

van Winsum, W., Brookhuis, K., and de Waard, D. (2000). A comparison of different ways to approximate time-to-line crossing (TLC) during car driving. *Accident Analysis and Prevention. 32*, 47-56.

## 6.6 Monitoring Lane Changes

*Introduction:*

As described in Table 5-1, lane change and merge related crashes were grouped under lane departures as a causal factor. In most of the other analyses that were reviewed, lane change crashes were typically combined with several other types of crashes; however, lateral encroachment during lane changes often due to improper mirror adjustment was listed as an at-risk driving behavior which is one of the top concerns among industry experts (Knipling, Hickman, and Bergoffen, 2003).

| Candidate Driver Behaviors for Onboard Monitoring |
|---|
| 1. Use of turn signal before merging |
| 2. Eye glances to the mirror before merging |
| 3. Did the driver adjust the mirrors before departing the yard |
| 4. Side or blind spot vehicle presence or position during lane changes |

*Driver Feedback Recommendations:*

| Recommended Driver Feedback Designs |
|---|
| 1. Delayed or off-line feedback with summary statistics |
| 2. A side object awareness and collision avoidance system |

Feedback on items such as turn signal use, mirror adjustments, and eye glances would best be provided off-line with summary statistics. If real-time monitoring of side or blind spot vehicles is possible, feedback would best be provided through a side object awareness and collision avoidance system.

*Additional Discussion:*

There has been much research on side object detection and side collision avoidance systems resulting from three NHTSA initiatives on the topic. Descriptions of these programs can be found on the NHTSA web site, link as follows: (http://www-nrd.nhtsa.dot.gov/departments/nrd-12/11rev.html). More recently, an SAE paper which may be of relevance (Smith, et al., 2003) discussed the feasibility of modeling lane-change performance using four states.

Eaton (http://www.vorad.com/) is one of the leading COTS manufacturers of commercial collision warning systems. The VORAD BlindSpotter is a currently available radar based side object detection system for truck applications. Delphi also has the Forewarn Radar Side Alert system (http://delphi.com/manufacturers/cv/safesecure/).

*Cross References:*

*See Section 6.5 (Lane Position)* - While Section 6.6 covers intentional lane changes, section 6.5 covers unintentional lane changes (lane departures).

*Key References:*

Knipling, R., Hickman, J., and Bergoffen, G. (2003). *Commercial Truck and Bus Safety Synthesis Program: Synthesis 1 - Effective Commercial Truck and Bus Safety Management Techniques.* Washington D.C.: Transportation Research Board.

Smith, D., Glassco, R., Chang, J., and Cohen, D. (2003). *Feasibility of Modeling Lane-Change Performance* (SAE Paper 2003-01-0280). Warrendale, PA: The Society of Automotive Engineers.

## 6.7 Monitoring and Recording Incidents

*Introduction:*

Industry experts (Knipling, Hickman, and Bergoffen, 2003) and truck drivers (Roetting, Huang, and McDevitt, 2005) both ranked several fuzzy behavioral concepts such as defensive driving skills, space management, anticipating traffic changes, and being ready to avoid the mistakes of other drivers as critical safety behaviors. Unfortunately, most of these concepts are difficult to measure directly, so one potential solution is to monitor, record, investigate, and teach drivers these skills through incident investigation.

| Candidate Driver Behaviors for Onboard Monitoring |
|---|
| 1. Hard braking incidents<br>2. Hard steering incidents<br>3. Close following distances (vehicle cut-ins)<br>4. Collision warning system activations<br>5. Crashes<br>6. Forward and/or driver video during the incident |

*Driver Feedback Recommendations:*

| Recommended Driver Feedback Designs |
|---|
| 1. Delayed or off-line feedback |

Feedback on the monitoring and recording of incidents would likely need to be part of a carefully constructed program that was presented to drivers in a non-threatening way. The goal of the program would be to have drivers examine and review near misses and other violent maneuvers in such a way that they might learn the skills necessary to avoid such incidents in the future.

The resulting analysis will be most effective as more and more data can be included about the incident, especially forward looking video and video of the driver at the time. Drivers will relate to and recall the details of the incident much better if video is provided. The inclusion of forward-looking video may be able to be sold as protection against liability in the case of a crash, since most crashes involving large trucks are not the fault of the truck driver. However, video of the driver may prove a difficult sell given privacy concerns.

*Additional Discussion:*

Several of the reviewed COTS devices record or flag various events. XATA records rapid stops and contains tools to reconstruct accidents with black box data. The Accident Prevention Plus system records vehicle data for 50 seconds before and 20 seconds after a crash, and the DriveCam system records both vehicle data an external video both before and after large g-force events or crashes. Finally, Eaton (http://www.vorad.com/) makes the VORAD Accident Reconstruction Technology, a product which combines vehicle data with the data received from a VORAD Forward Collision Warning system to graphically reconstruct crashes.

*Cross References:*

*See Section 6.4 (Hard Braking Incidents)* - Hard braking incidents are discussed in detail in Section 6.4.

*Key References:*

Knipling, R., Hickman, J., and Bergoffen, G. (2003). *Commercial Truck and Bus Safety Synthesis Program: Synthesis 1 - Effective Commercial Truck and Bus Safety Management Techniques.* Washington D.C.: Transportation Research Board.

Roetting, M., Huang, Y., McDevitt, J.R., Melton, D., Smith, G.S. (2005). Feedback by technology: Attitudes and opinions of truck drivers. *Transportation Research Part F 8.* pp. 277-297.

## 6.8 Monitoring Fatigue

*Introduction:*

Industry experts ranked fatigue or drowsy driving as number six out of their top nine safety concerns (Knipling, Hickman, and Bergoffen, 2003), and drivers ranked it as number five out of their top ten (Roetting, Huang, and McDevitt, 2005). However, European crash data has shown that fatigue was a causal factor in only 5.3 percent of truck crashes (Häkkänen and Summala, 2001), and Large Truck Crash Causation Study (LTCCS) found similar results, suggesting that only 4 percent of crashes could be attributed to sleep or sleep related to illness.

| Candidate Driver Behaviors for Onboard Monitoring |
|---|
| 1. Driver eye movements<br>2. Lane position |

*Driver Feedback Recommendations:*

| Recommended Driver Feedback Designs |
|---|
| 1. Real-time drowsy driver detection and warning system |

Fatigue or drowsy driving can result in an immediate threat if left unchecked; short breaks, naps, and even a simple cup of coffee at the right moment can be a highly effective countermeasure to fatigue as our bodies tend to work in cycles or rhythms. The goal of any fatigue feedback system should be first and foremost to assist the driver in determining when best to stop and take a break. A second goal might be to educate or convince a driver that a break is necessary, and finally, the feedback should be able to warn or wake a driver engaged in microsleeps. One novel feedback interface exists on the Copilot driver fatigue monitoring system by Attention Technologies (http://www.attentiontechnology.com/), whose user-centered design is detailed in Ayoob, Grace, and Steinfeld (2003).

*Additional Discussion:*

There is distinction that should be made between the terms and concepts of fatigue and drowsy driving. Fatigue, which is often lumped together with drowsy driving on surveys, may carry certain connotations which could affect how highly it has been rated as a problem by drivers compared to the actual crash statistics. Fatigue represents an entire continuum which ends in drowsy driving. Noticeable changes occur and increase with the onset of fatigue such as feelings of tiredness, a lack of the ability to focus attention, decreased working memory, slowed reactions times, and tunnel vision in eye scan patterns. Some of indicators were specifically reported with solo long-haul truck drivers in Hartley, et al. (1994). A recent paper by Williamson, et al. (2001) further detailed and characterized some of the cognitive and motor skill performance decrements that can be associated with fatigue. Moderate stages of fatigue may mimic distracted driving, resulting in a general, overall, increased crash risk. This is generally believed to be one of the reasons why crashes occur more frequently during evening commutes rather than during morning commutes.

As fatigue slowly builds, sometimes over a series of hours, it becomes drowsy driving which can be characterized by extreme tunnel vision and microsleeps. One fatigue or drowsy driving detection method or measure that has been researched, validated, and extensively tested is PERCLOS. Simply put, PERCLOS is the percentage of eye closure, and some of the early work on the measure can be found in Weireille, et al. (1994) and Dinges, et al. (1998). At least one COTS fatigue monitoring device utilizing PERCLOS is available, the Copilot which is made by Attention Technologies (http://www.attentiontechnology.com/).

Steering entropy, a measure of lane keeping performance, has also been recently proposed as a surrogate measure for fatigue (Paul, Boyle, Boer, Tippin, and Rizzo, 2005).

<u>*Cross References:*</u>

*See Section 6.2 (Following Distance)* - One possible result of driver's falling asleep at the wheel is a rear-end collision, and a forward collision warning system may also prove a useful countermeasure.

*See Section 6.3 (Attention)* - The stages of fatigue can result in similar performance decrements as seen with inattention, so similar monitoring techniques may prove useful to both.

*See Section 6.5 (Lane Position)* - One likely result of driver's falling asleep at the wheel is a lane departure, so lane position may be a surrogate for drowsy driver detection, and a lane departure warning system may also prove a useful countermeasure.

*See Section 6.9 (Hours of Service)* - One surrogate to measuring fatigue directly is monitoring hours of service.

<u>*Key References:*</u>

Ayoob, E., Grace, R., and Steinfeld, A. (2003). A user-centered drowsy-driver detection and warning system. *Proceedings of the 2003 conference on Designing for user experiences.* New York, NY: Associations for Computing Machinery (ACM).

Dinges, D., Mallis, M., Maislin, G., Powell, J. (1998). *Evaluation of Techniques for Ocular Measurement as an Index of Fatigue and as the Basis for Alertness Management* (DOT HS 808 762). Washington, DC: National Highway Traffic Safety Administration.

Häkkänen, H. and Summala, H. (2001). Fatal traffic accidents among trailer truck drivers and accident causes as viewed by other truck drivers. *Accident Analysis and Prevention. 33*, 187-196.

Hartley, L.R., Arnold, P.K., Smythe, G., and Hansen, J. (1994). Indicators of fatigue in truck drivers. *Applied Ergonomics.* 143-156.

Knipling, R., Hickman, J., and Bergoffen, G. (2003). *Commercial Truck and Bus Safety Synthesis Program: Synthesis 1 - Effective Commercial Truck and Bus Safety Management Techniques.* Washington D.C.: Transportation Research Board.

Paul, A., Boyle, L., Boer, E., Tippin, J., and Rizzo, M. (2005). Steering Entropy Changes as a Function of Microsleeps. *Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design.* Iowa City, IA: The University of Iowa. [Available Online at http://ppc.uiowa.edu/driving-assessment/]

Roetting, M., Huang, Y., McDevitt, J.R., Melton, D., Smith, G.S. (2005). Feedback by technology: Attitudes and opinions of truck drivers. *Transportation Research Part F 8.* pp. 277-297.

Wierwille, W., Ellsworth, L., Wreggit, S., Fairbanks, R., Kirn, C. (1994). *Research on vehicle based driver status/performance monitoring: development, validation, and refinement of algorithms for detection of driver drowsiness* (DOT HS 808 247). Washington, DC: National Highway Traffic Safety Administration.

Williamson, A., Feyer, A., Mattick, R., Friswell, R., Finlay-Brown, S. (2001). Developing measures of fatigue using an alcohol comparison to validate the effects of fatigue on performance. *Accident Analysis and Prevention. 33*, 313-326.

## 6.9 Monitoring Hours of Service

*Introduction:*

The maximum hours of service a driver can perform is specified in both Federal and State regulations. These limits have been placed, in part, to guard against driver fatigue. Drivers are required to keep logs to determine compliance the mandatory hours of service requirements, and the requirements for an automatic monitoring system have already been laid out in both the federal and the state codes which are listed below.

| Federal Regulation CFR III-395.15 of Title 49: Requirements for Automatic On-Board Monitoring of Hours of Service | |
|---|---|
| 1. | Duty status: off duty, sleeper berth, driving, or on-duty not driving; |
| 2. | Date |
| 3. | Total miles driven today |
| 4. | Truck or tractor and trailer number |
| 5. | Name of carrier |
| 6. | Main office address |
| 7. | 24-hour period stating time |
| 8. | Name of co-driver |
| 9. | Total hours |
| 10. | Shipping document number or name of shipper and commodity |
| 11. | For each change of duty status, the name of the city, town, or village, with State abbreviation, shall be recorded. |

| California Code Section 1213.2: Requirements for Automatic On-Board Monitoring of Hours of Service | |
|---|---|
| 1. | Engine use |
| 2. | Road speed |
| 3. | Miles driven |
| 4. | Date |
| 4. | Time of day |
| 6. | Duty status |
| 7. | Multiple drivers |

*Driver Feedback Recommendations:*

| California Code Section 1213.2<br>Feedback Requirements for Automatic On-Board Monitoring of Hours of Service |
|---|
| Automatic on-board recording devices should produce an electronic display or printout (on demand) of a driver's hours of service, showing the time, sequence, and location of duty status changes including the driver's starting time at the beginning of each day.<br><br>Automatic on-board recording devices with electronic displays shall have the capability of displaying the following:<br><br>1. Driver's total hours of driving<br>2. Total hours on duty today<br>3. Total miles driven today<br>4. The sequential changes in duty status, and the times and locations where changes occurred for each driver. |

*Additional Discussion:*

The maximum hours of operation as defined by federal and state codes and regulations are compared below. Federal regulations apply for interstate travel, but the California State code, which is somewhat more relaxed, applies for intrastate travel. In addition to the federal and state regulations, the Transportation Research Board has published a guide on hours of service and fatigue management techniques (Brock, Golembiewski, Krueger, Daecher, Bishop, and Bergoffen, 2005).

| CFR Title 49, Subtitle 3, Chatper III,<br>Section 395.3 | In California Vehicle Code<br>Section 34501.2: |
|---|---|
| (1) May drive a maximum of 11 hours after 10 consecutive hours off duty.<br>(2) May not drive beyond the 14th hour after coming on duty, following 10 consecutive hours off duty.<br>(3) May not drive after 60/70 hours on duty in 7/8 consecutive days.<br>(4) CMV drivers using a sleeper berth provision must take at least 8 consecutive hours in the sleeper berth, plus 2 consecutive hours either in the sleeper berth, off duty, or any combination of the two. | (1) The maximum driving time within a work period shall be 12 hours for a driver of a truck or a truck tractor, except for a driver of a tank vehicle with a capacity of more than 500 gallons transporting flammable liquid, who shall not drive for more than 10 hours within a work period.<br>(2) No motor carrier shall permit or require a driver to drive, nor shall any driver drive, for any period after having been on duty for 80 hours in any consecutive 8 days.<br>(3) Exceptions include drivers hired by:<br>a. Water, electrical, and gas corporations.<br>b. Governmental fire and law enforce departments.<br>c. Agricultural carriers (different restrictions apply). |

Electronic onboard recorders (EOBR) have been available for completing records of duty status (RODS) fulfilling operator hours of service (HOS) regulations since 1988. Three current COTS devices which are currently on the market are described below.

| Company | Features | | | | | |
|---|---|---|---|---|---|---|
| | CFR49 Part 395.15 Compliance | GPS-based Location Recording | Wireless Commu-nication | Vehicle Speed | Two-way Text Message | Fuel Consumption Evaluation |
| Karta | × | × | × | × | × | |
| Nextel | × | × | × | × | × | × |
| Tripmaster | × | × | | × | | × |

Karta's TransTRAK (also known as planetTRAKS) system is a vehicle tracking system that is designed to deliver real-time vehicle location, speed, distance monitoring, and data on numerous other vehicle events. The bonus features of this system consist of: (1) GPS-based positioning, routing, and "geofences", (2) asset tracking, and (3) two-way text messaging system. This system can automate the collection and reporting of driver duty status information.

Nextel's XORA system is a JAVA- and GPS-enabled phone that is designed to deliver real-time user location, speed, distance monitoring. The bonus features of this system consist of: (1) GPS-based positioning, routing, and "geofences" and (2) phone alerts for HOS violations. The advantage of this system is that the EOBR functions have been built into a cell phone.

The purpose of Tripmaster's suite of products is to assist in basic federal compliance reporting requirements, such as computing fuel and mileage tax and driver logs . The additional features of this system include: (1) GPS-based positioning and (2) over-speed continuous warning beeper.

*Cross References:*

*See Section 6.8 (Fatigue)* - Monitoring hours of service may be considered surrogate to measuring fatigue directly.

*Key References:*


Brock, J., Golembiewski, G., Krueger, G., Daecher, C., Bishop, R., Bergoffen, G. (2005). *Commercial Truck and Bus Safety Synthesis Program: Synthesis 7- Motorcoach Industry Hours of Service and Fatigue Management Techniques.* Washington D.C.: Transportation Research Board.

California Code of Regulations, Title 13 Motor Vehicles, Division 2 Dept. of CHP, Chapter 6.5 Motor Carrier Safety, Article 3 General Driving Requirements, Section 1213.2 Automatic Onboard Recording Devices.

California Vehicle Code, Division 14.8 Safety Regulations, Section 34501.2 Limitations: Driving Hours.

Code of Federal Regulations, Title 49, Subtitle 3, Chapter III, Sections 395.3 and 395.15.

Nextel's XORA website: http://www.nextel.com/en/solutions/gps/xora.shtml

planetTRAKS website: http://www.planettraks.com/

Tripmaster's website: http://www.tripmaster.com/

## 6.10 Monitoring Behaviors at Intersections - I have to finish the text for this

*Introduction:*

The large truck crash causation study (LTCCS) found that intersection related crashes accounted for approximately 27 percent of the crashes caused by truck drivers, which was the third largest category of critical events. As described in Table 5-2 intersection crashes can result from poor scanning, failures in perception, and poor decisions. The LTCCS, in Table 4-8, found that, overall, 46 percent of the crashes were primarily the result of inattention or distraction, and 36 percent were primarily caused by driver decisions (misjudgments). Unfortunately, without knowing exact vehicle locations, it's very difficult to monitor or critique driver decisions. While this may become possible in the future with the advent of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, several near term possibilities for intersection behavior monitoring are listed below.

| Candidate Driver Behaviors for Onboard Monitoring |
|---|
| 1. Stopping for stop signs |
| 2. Stopping for red lights |
| 3. Eye glance patterns, i.e., checking for cross traffic when leaving a 2-way stop sign |

*Driver Feedback Recommendations:*

| Recommended Driver Feedback Designs |
|---|
| 1. Delayed or off-line feedback |
| 2. Real-time stop sign or red light violation warning system |

Feedback for intersection behavior monitoring would best be provided through off-line with summary statistics. A real-time feedback system for these events would not be recommended since the driver would already be aware of the event, and the event would be completed by the time the system could react. Useful feedback on these events may come from reviewing event frequency over time. While the driver may be aware of an individual event, the driver may not realize how often those events happen.

Alternatively, there has been recent and ongoing research (FHWA, 2004) on the topic of stop sign and red light violation warnings. This research should eventually result in specifications on how to predict violations and provide the driver with real-time feedback in the form of a warning system.

*Additional Discussion:*

While enhanced maps might provide the locations of stop signs and traffic signals, detecting the current phase of the traffic signal can probably only be achieved through video detection and processing. In there near future, there may be the possibility of getting traffic signal state automatically through V2I communications.

Checking eye glance scanning patterns, although possible, would probably provide little useful information. Intersection scanning is complex, and not well understood. Additionally, scanning does not necessarily result in seeing or perceiving, as is evident by the crash causation category of “looked, but did not see.”

<u>*Cross References:*</u>

*See Section 6.3 (Attention)* - Intersection crashes may also result from inattention or distraction.

<u>*Key References:*</u>

Turner-Fairbank Highway Research Center (2004). *Update on Intelligent Vehicles and Intersections.* Washington, D.C.: Federal Highway Administration. [Online Newsletter Available at http://www.tfhrc.gov/pubrds/04jan/08.htm]

### 6.11 Monitoring Other Vehicle Parameters - SLK Working on it

*Introduction:*

In this section, other vehicle parameters include engine RPM, acceleration, gear position, throttle position, clutch position, fuel rate, etc. The reasons of monitoring these parameters can be divided into three categories:

(1) *Incident reconstruction:* in general, vehicle locations, speeds, and accelerations can be used to reconstruct vehicle trajectories during an accident. Since some of these sensors may not work accurately when incidents occur, the redundancy of the sensor information can be very helpful.

(2) *Prevention of vehicle abuse:* two examples are used to illustrate the incentive to monitor vehicle abuse. First, running engines at high RPM frequently can result in abnormal engine wear. The second example is that for vehicles with manual transmission, depressing clutch pedals halfway can cause additional clutch wear or gear damage. As a result, monitoring engine RPM, clutch positions, throttle positions, etc, can help prevent abuse by drivers.

(3) *Fuel economy:* one of the concerns from fleet managing teams is the fuel economy. From the aspect of public health, good fuel economy implies less air pollution. Combining throttle positions, gear positions, fuel rate, and engine RPM, one can determine if drivers have good driving habits to "save some gas".

| Candidate Driver Behaviors for Onboard Monitoring |
|---|
| 1. Engine RPM (engine over speed)<br>2. Appropriate gear selection<br>3. Use of low gears to save brake when driving on slopes<br>4. Fully depressing/releasing clutch (for vehicles with manual transmission)<br>5. Driving time<br>6. Non-driving time<br>7. Engine idle time<br>8. Acceleration<br>9. Deceleration<br>10. Fuel Rate/Fuel Economy |

*Driver Feedback Recommendations:*

| Recommended Driver Feedback Designs |
|---|
| 1. Delayed or off-line feedback |

Much of the information described in this section is not essential to be displayed in real-time, and those items that are essential already have driver displays.

*Additional Discussion:*

A listing of COTS systems and the auxiliary vehicle parameters monitored by each is provided below. While these parameters may not always be safety related, fuel economy and vehicle maintenance translate to direct cost savings for management, making them desirable additions to any onboard monitoring system.

| | Mileage | Engine RPM | Acceleration | Gear Position | Throttle Position | Fuel Rate | Clutch Position |
|---|---|---|---|---|---|---|---|
| XATA | × | × | | | × | × | × |
| Delphi | × | | | | | | |
| APPlus | | × | × | × | | × | |
| Cadec | × | × | | | | | |
| QualCOMM | × | × | | | × | | |
| DriveCam | | | × | | | | |

Another example is Eaton's VORAD Information Management System (EVIMS). It analyzes safety trends for drivers and vehicles, benchmarks safety goals for the fleet, and identifies drivers who do meet those goals. The EVIMS does this by comparing individual driver and vehicle performance to fleet averages. Additional features include braking & fuel economy, time on brake, and slow traffic reports.

*Cross References:*

*See Section 6.4 (Hard Braking Events).*

*See Section 6.7 (Recording Incidents).*

*Key References:*

APPlus: At the time of this report, current information on this company could not be found.

Cadec's Mobile Information System website: http://www.cadec.com/

Delphi's TruckSecure is offered by MobileAria at the following website:
http://www.mobilearia.com/prodserv/trucksecure.shtml

DriveCam's website: http://www.drivecam.com/

Eaton's EVIMS is marketed and sold through its RoadRanger subsidiary at the following website: http://www.roadranger.com/

QualCOMM's SensorTRACS website:
http://www.qualcomm.com/qwbs/solutions/prodserv/sentracs.shtml

XATA's website: http://www.xata.com/

# Onboard Monitoring System Specification

# SYSTEM SPECIFICATION

**for the**

**Onboard Monitoring System for
Commercial Motor Vehicle Safety
Task Order: 5609**

**Release 1, Version 1
February 28, 2006**

**Prepared for:**

**United States of America
Department of Transportation
Federal Highway Administration**

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# Onboard Monitoring System Specification

## 1. INTRODUCTION

1.1 **Scope of Document**: This document established the preliminary system requirements for the Onboard Monitoring System (OBMS) that will be built for Field Operational Test (FOT) and evaluation. The functional requirements and design constraints for OBMS are defined in this document.

1.2 **Mission**: European studies have shown up to 30% reduction in crash rates for vehicles equipped with onboard recorders. This experience could be adapted to the United States trucking industry. The Onboard Monitoring System for Commercial Motor Vehicles is a government-industry-academia collaboration to demonstrate that the application of monitoring drivers will improve the safety highway and urban travel. This monitoring system can provide a mechanism to encourage good driving behavior by recognizing and correcting self-induced hazardous driving situations.

# Onboard Monitoring System Specification

## 2. SYSTEM OVERVIEW

2.1 **System Definition**: The Onboard Monitoring System is a system that (1) records and monitors hours of service, driver input commands, vehicle states, and environmental conditions and (2) provides recommended driving behavior by using real-time feedback devices or offline feedback procedure. This OBMS can be installed in any commercial motor vehicles with the required interface.

Figure 2.1 shows the Onboard Monitoring System diagram. It is clear that OBMS consists of six subsystems:

- Core system
- Sensing equipments
- Data storage devices
- Real-time feedback devices
- Driver input devices
- Offline analysis tools.

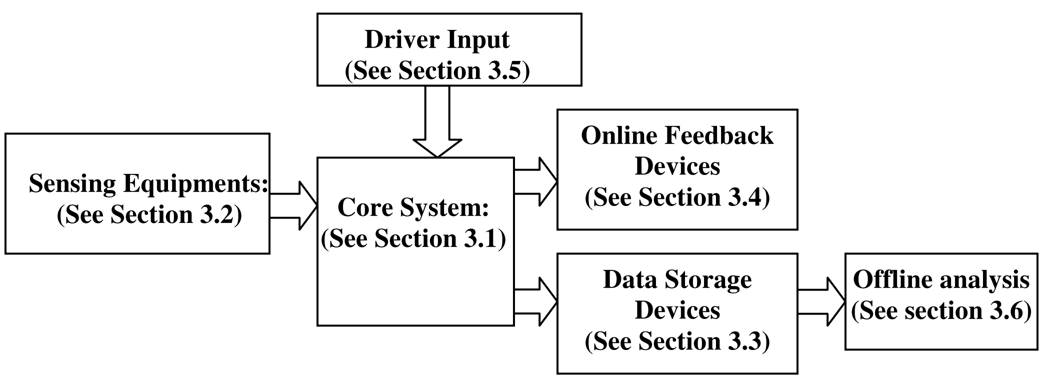


Figure 2.1: general OBM system diagram

In general, as the driver begins travel, the core system acquires information from sensing equipments. This core system then monitors driving behavior based on the acquired information. To determine if the driving behavior is good or not, the core system shall have recommended driving behavior as the reference. By comparing the two driving characteristics, the core system shall take the following actions: (1) sending signals to online feedback devices to warn drivers, (2) saving event data into the storage devices, or (3) performing both action (1) and (2). The data recorded in the storage devices shall be analyzed and processed by fleet management teams after the driver finishes tasks. The functional or performance requirements of the six respective subsystems are presented in Section 3.1 through Section 3.6.

2.2 **Operating Modes**: The OBMS Operating Modes are listed as follows:

- Normal monitoring and recording - normal driving conditions
- Incident recording - events and incidents
- Memory access mode (e.g., when vehicle is pulled over in order to check electronic logs by authorities)
- Idle mode - when ignition is off.

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## SYSTEM REQUIREMENTS

3.1 **<u>Functional Requirements for Core System</u>**: The OBMS shall be designed to implement the functional requirements called out in this section. Based on the Concept of Operation, the functional requirements are listed as follows.

3.1.1 **<u>Monitoring driving behaviors related to vehicle speed</u>**: The OBMS shall observe the following driving behaviors related to vehicle speed and conduct the recommended feedback approaches.

3.1.1.1 **<u>Vehicle speed relative to speed limit</u>**: The OBMS shall monitor vehicle speed relative to roadway speed limit. This shall require information from wheel speedometer, vehicle location from GPS system, and GIS information from database. For example, NAVTEQ's product can provide such GIS information. The speed violation shall be recorded in the storage devices and a visual/audible warning shall be given to the driver.

3.1.1.2 **<u>Vehicle speed relative to safe curve speed</u>**: The OBMS shall provide safe curve speed. This can be done by using Rollover Stability Advisor (RSA) system. For example, Freightliner's RSA system can provide the safe curve speed. The feedback approach for unsafe speed is **TBD**.

3.1.1.3 **<u>Vehicle speed relative to roadway (weather) condition</u>**: The OBMS shall provide offline analysis on the roadway and weather conditions by using information, such as stored regional weather map, wiper usage, and outside temperature. This analysis processed by the analysis tools of the fleet management team shall determine unsafe speed during driving. The feedback approach for unsafe speed is **TBD**.

3.1.1.4 **<u>Vehicle speed relative to traffic flow</u>**: The OBMS shall use Radar/Lidar sensor information to determine the current traffic condition. For example, Eaton VORAD EVT-300 with lane change detection shall provide such information. The feedback approach for unsafe speed is **TBD**.

3.1.2 **<u>Monitoring following distance</u>**: The OBMS shall examine the following driving behaviors related to following distance and determine feedback methods.

3.1.2.1 **<u>Following too close for travel speed and trailer loading</u>**: The OBMS shall combine Radar/Lidar sensor information with speedometer reading to determine unsafe following distance. Quantity of trailer loading is prerequisite information input to the OBMS before driving. The OBMS shall provide real-time feedback in the form of a warning/status light. Delayed or off-line feedback with summary statistics shall be given to the driver.

3.1.2.2 **Following too close for weather conditions**: The OBMS shall provide offline analysis on the roadway and weather conditions by employing information, such as stored regional weather map, wiper usage, and outside temperature. The analysis processed by the analysis tools for the fleet management team shall identify unsafe following distance stored in storage devices. The feedback approach for the unsafe following distance is **TBD**.

3.1.3 **Monitoring driver attention**: The OBMS shall perform offline analysis to determine driver attention. This can be done by using surrogate measures, such as steering input measurements, lane position, and hard braking events. The offline feedback with summary statistics shall be given to the driver.

3.1.4 **Recording hard braking events**: The OBMS shall record the engineering details and forward looking video surrounding the hard braking event. This requires speedometer, accelerometer, and video camera. For example, DriveCAM is such a product that combines accelerometer and video camera. Delayed or off-line feedback with summary statistics shall be given to the driver.

3.1.5 **Monitoring lane position**: The OBMS shall monitor the lane position and the steering input of the vehicle. A lane departure warning system shall be employed in the FOT. For example, Assistware's systems can provide lane position with respect to the lane marking. Such commercial systems can provide real-time lane departure warning in the form of a visual/audible warning. Delayed or offline feedback with summary statistics shall be given to the driver.

3.1.6 **Monitoring lane changes**: The OBMS shall monitor examine the following driving behaviors related to lane changes and determine feedback methods.

3.1.6.1 **Use of turn signal before merging**: The OBMS shall combine the lane departure system with the turn signals to observe habits of using turn signals. Delayed or off-line feedback with summary statistics will be given to the driver.

3.1.6.2 **Side or blind spot vehicle presence during lane changes**: The OBMS shall use the side collision warning system to determine blind spot vehicle

# Onboard Monitoring System Specification

presence. The side collision warning system shall provide real-time feedback in the form of a visual/audible signal to the driver. Delayed or offline feedback with summary statistics shall be given to the driver.

3.1.7 **Recording events and incidents**: The OBMS shall record the following incidents.

3.1.7.1 **Hard braking incidents**: See Section 3.1.4.

3.1.7.2 **Hard steering incidents**: The OBMS shall determine and record hard steering incidents based on vehicle speeds, steering inputs, and accelerometer readings. Delayed or off-line feedback with summary statistics based on recorded data shall be given to the driver.

3.1.7.3 **Close following distance (vehicle cut-ins)**: The OBMS shall record the engineering details and video such events. The offline analysis shall be used to determine vehicle cut-ins. Also see Section 3.1.2.

3.1.7.4 **Collision Warning Activations**: See Section 3.1.2 and 3.1.6.2.

3.1.7.5 **Crashes**: The engineering details and video shall be recorded before and after the crash for incident reconstruction.

3.1.8 **Monitoring driver fatigue**: The OBMS shall incorporate the lane departure warning system to examine driver fatigue. The lane departure warning system shall give a real-time visual or audible warning to the driver.

3.1.9 **Recording hours of service**: The OBMS shall record hours of service which has compliance with Federal Regulation CFR III-395.15 of Title 39 and California Code Section 1213.2. For example, ACTIA's product can be used to record such HOS information.

3.1.10 **Monitoring driving behavior at intersections**: The OBMS shall incorporate GPS/GIS and speedometer information to determine if the vehicle stops for stop signs. It shall give real-time feedback in the form of a visual/audible warning to the driver. Delayed or off-line feedback with summary statistics based on recorded data shall be given to the driver.

3.1.11 **Monitoring other vehicle parameters**: The OBMS shall monitor vehicle parameters, such as engine RPM (especially engine over speed), fully depressing/releasing clutch (for vehicles with manual transmission), driving time, non-driving time, engine idle time, acceleration/deceleration, and fuel rate/fuel economy. These vehicle parameters may have potential influence on safety. The OBMS shall record such information for off-line analysis.

3.1.12 **System Fault Detection**: The OBMS shall have self-diagnosis function to detect system malfunction/fault. Any malfunction/fault with time stamps shall be recorded in the data storage devices.

3.1.13 **System Tamper-Proof**: The OBMS shall be tamperproof. The system shall not allow the driver to access recorded data.

3.2 **Performance Requirements for Sensing Equipment**: The OBMS shall have the following sensing components and systems:

3.2.1 **On-board vehicle sensors information from J-BUS**: The OBMS shall be able to acquire information from on-board vehicle sensors, such as wheel speeds, engine RPM, brake activation (on/off), clutch activation (on/off), etc.

3.2.2 **Accelerometers**: The accelerometers shall have the capability to record acceleration/deceleration at normal driving conditions and during crashes.

3.2.3 **Lane departure warning system**: The lane departure warning system shall provide relative lane position with respect to lane markings.

3.2.4 **Rollover stability advisor system**: The rollover stability advisor system shall provide safe curve speed.

3.2.5 **Forward and side collision warning systems**: The forward and side collision warning systems shall provide the following information: (1) relative speed between the leading vehicle and the monitored vehicle itself, (2) relative distance between the two vehicles, and (3) collision warning signals with respect to the monitored vehicle speed.

3.3 **Functional Requirements for Data Storage Devices**: The data storage devices shall have the following features.

3.3.1 **Anti-shock**: The data storage devices shall have the capacity to tolerate shocks up to 30g.

3.3.2 **Reliability requirements**: The data storage devices shall not have any damaged memory during the system life cycle.

# Onboard Monitoring System Specification

3.3.3 **Enough capacity**: The data storage devices shall have enough space to include normal driving data and to record the video and engineering data in the required maximum number of incidents.

3.4 **Requirements for Onboard Feedback Devices**: The onboard feedback devices shall have the capability to give visual or audible signals to the driver. Such devices shall not distract the driver from driving too much.

3.5 **Requirements for Driver Input Devices**: The OBMS shall use electronic ID cards to identify drivers. For example, many COTS systems utilize smart cards to conduct this task. The driver input devices shall have the interface that allows drivers to input required information, e.g. duty status required in HOS.

3.6 **Requirements for Offline Analysis Tools**: The offline analysis tools shall have the capability to perform the tasks as described in Section 3.1.

## 4. SYSTEM DESIGN CONSTRAINTS

**Environmental Design Considerations**:

4.1.1 **Temperature**: The operating ambient air temperature range is 125$^\circ$F to -55$^\circ$F for operating conditions and 200$^\circ$F to -55$^\circ$F for non-operating conditions.

4.1.2 **Relative humidity**: The OBMS shall be designed to perform within the ambient relative humidity range of 0% to 100%.

4.1.3 **Atmospheric pressure**: The OBMS shall be designed to perform when exposed to absolute pressure (not corrected to sea level) between 16.8 and 31.4 inches of mercury (427 and 797 millimeters of mercury, respectively).

4.1.4 **Solar radiation**: The OBMS shall be designed to withstand the levels of solar radiation as indicated by the ranges below:

4.1.4.1 **Total solar radiation**: The following spec defines the solar radiation exposure conditions for OBMS components. Total solar radiation is defined as wavelengths between 295 nm and 2800 nm.

a. The maximum instantaneous solar radiation on a horizontal surface is 67 $\mathrm{kJ/(m^2 \cdot min)}$.

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b. The maximum daily solar radiation on a horizontal surface is 32.7 $\text{MJ/m}^2$.
c. The maximum annual solar radiation on a horizontal surface is 7,750 $\text{MJ/m}^2$.

4.1.4.2 **Ultraviolet radiation**: The following spec defines the ultraviolet radiation exposure conditions for the OBMS. Ultraviolet radiation is defined as wavelengths between 295 nm and 385 nm.
a. The maximum instantaneous ultraviolet radiation on a horizontal surface is 2.9 $\text{kJ/(m}^2 \cdot \text{min)}$.
b. The maximum daily ultraviolet radiation on a horizontal surface is 1.4 $\text{MJ/m}^2$.
c. The maximum annual ultraviolet radiation on a horizontal surface is 346 $\text{MJ/m}^2$.

**Hardware Design Considerations**: The hardware design consists of two parts: (1) in vehicle and (2) in dispatch. The hardware used in vehicles and dispatch shall be designed based on ease and convenience of drivers and fleet users.

4.2.1 **Hardware in vehicles**: The design for hardware in vehicles shall consider the following issues.

4.2.1.1 **Driving and vehicle safety**:
a. Any hardware in the OBMS shall not block driver sight.
b. It shall not interfere with original equipments in the vehicle.
c. The maximum current flow in the OBMS shall not exceed a pre-defined value (a safety limit).

4.2.1.2 **Ease of learning**: The human-machine interface in the OBMS shall be easy to learn. For example, a simple faceplate design with a few buttons is highly desirable such that drivers can be trained in minutes.

4.2.1.3 **Tamper-proof design**: The data storage devices shall be designed in an easy-to-remove manner. However, the interface used in the data storage devices shall be customized to avoid unauthorized data access. See also Section 3.1.13.

4.2.1.4 **System security**: Most of the hardware in vehicles shall be invisible, with one exception: human-machine interface.

# Onboard Monitoring System Specification

4.2.2 **Hardware in dispatch**: The hardware used in the fleet management team shall be computers only. A customized interface is required in order to download files from the data storage devices.

**Software Design Considerations**: The software design can be divided into two parts: (1) in vehicle and (2) in dispatch. The design concerns are listed as follows.

4.3.1 **Software in vehicles**: The software used in vehicles shall be designed in an upgradeable manner. The OBMS may include new functions and more updates later.

4.3.2 **Software in dispatch**:

4.3.2.1 "**One-click" design**: The software designed for the fleet management team shall be "one-click" design. That is, with one click on the mouse the computers shall download the data and generate analysis reports automatically.

4.3.2.2 **Upgradeable design**: The software shall be able to incorporate new patches and include additional features in the future. See also Section 4.3.1.

## 5. NOTES

5.1 **Glossary**:

| | |
|---|---|
| Design Constraint | It expresses limitations or boundaries in which a design solution must stay. |
| Functional Requirement | An unambiguous and verifiable statement of what is Wanted, or what is to be accomplished. |
| Performance Requirement | A negotiated value which answers the question of "how much" and "how well" i.e., units and tolerances. |
| Vehicle State | An expression of the vehicle's position, velocity, and acceleration. |

5.2 **Acronyms, Abbreviations, and Symbols**:

| | |
|---|---|
| COTS | Commercial Off-The-Shelf |
| OBMS | On-Board Monitoring System |
| HOS | Hours Of Service |
| TBD | To Be Determined |

Onboard Monitoring and Reporting for Commercial Motor Vehicle Safety

# System Engineering Management Plan

Version 1 | 12/21/2005

## Foreword

This document outlines the System Engineering Management Plan (SEMP) for the OBMVS PATH project. The Onboard Monitoring and reporting for commercial motor Vehicle Safety (OBMVS) project starts as a 14-month research effort that will define the concept of an integrated safety monitoring system and turn it into a prototype. This will be followed closely by a field operational test (FOT) for which a plan will be specified during the research phase. The SEMP spells out system engineering process that will be applied as well as the project plan.

As part of the product life cycle, the SEMP will be finalized once the design of the product is complete. This will be the version 2 of the SEMP. The present document is version 1. The two versions differ in the following ways:

### *SEMP Version 1*

The first version of the SEMP spells out the system engineering process, the engineering disciplines and technical plans, and the scope of work, including schedules, milestones and a list of deliverables. The project control points are highlighted, but the verification and validation plans are not presented yet, as they require that the system requirements be known.

### *SEMP Version 2*

The second version of the SEMP will be produced once the architecture and the design are defined. It will reference the system verification plan for the system and testing plans for the subsystems. Additionally, it will freeze the adjustment that will be made throughout the first half of the project and refine the sections for which unveiling the concept of operations, requirements and design clarify the objectives and constraints.

# 1 Introduction

## 1.1 Project summary

The University of California Partners for Advanced Transit and Highways (PATH) and the California Center for Innovative Transportation (CCIT), both part of the Institute of Transportation Studies (ITS), are collaborating on this project to improve truck safety via onboard monitoring and reporting of variables that may precede crashes. The project is funded by the Federal Motor Carrier Safety Administration (FMCSA) through the California Department of Transportation (Caltrans). Both are considered project stakeholders.

The project team will look for a commercial trucking company ("partner carrier") that is interested in becoming a partner in this project and in participating in a field test by early 2007. The current phase is a fourteen-month effort to define the concept of operations, specify and develop a single prototype, and test it on a Class 8 tractor owned by Caltrans (the "project truck"). A subsequent project would be the field test, consisting of a limited deployment of the product of the present research project on a fleet of commercial vehicles. The methodology and the protocol employed for the field test will be determined as part of the present project.

If the prototype can demonstrate a significant potential to reduce truck accidents, the following step will be an attempt to turn the prototype into a commercially available product. One of the reasons of CCIT's involvement is to prepare this deployment stage.

## 1.2 Document scope

The System Engineering Management Plan (SEMP) describes the system engineering approach applicable to the project and presents the work plan. The SEMP is intended as a project roadmap that the project team and the project sponsor can refer to. It spells out what the project team will do and how it will accomplish it.

The document consists of two main sections, numbered 3 and 4. The first one describes the system engineering process itself in the context of this project. In particular, it shows how the environment and the constraints surrounding this project have shaped the planning of the workflow. The first section also presents each engineering discipline applicable to the project, and how the activities of these disciplines fit into the development process as a whole. The engineering specialties are the human factors, the hardware engineering, the software engineering, the data intelligence and the experiment design, systems engineering and deployment team.

The second part of this document is the overall project plan. That section includes the scope of work, the schedule, the deliverables, the project resources and the project management structure.

### 1.3 Applicable documents

- California PATH, Statement of Work, OBMVS – June 2005.
- California PATH, Kick-off meeting slide show, OBMVS – June 2005

## 2 System engineering process

### 2.1 Process intent and overview

This project is a 14-month effort involving a multi-disciplinary team and a commercial partner yet to be determined. Its main deliverable will be a functioning prototype of an onboard monitoring system that processes inputs from various truck sensors and outputs safety metrics and warnings that are fed back to the drivers.

Because the prototype will be a complete system with hardware and software components, built for an operational environment with which it will interact tightly, it is appropriate to use a system engineering framework. The system engineering process intends to insure that the research product will be the result of a concerted effort to derive design and development from well-defined requirements, and to harmoniously integrate the different engineering disciplines.

The ultimate goal of this project is to turn the prototype to the industry so that truck carriers can benefit from enhanced safety features that could reduce the number of crashes and fatalities. System engineering will enable the transition from research to industry by forcing a rigorous and well-documented development process from the early stages. If a deployed commercial system is considered the ultimate outcome of the OBMVS research, then this project is the first iteration in a more global product development process.

While the expectation that the project delivers a functioning system underlines the needs for a system engineering process, some adjustments had to be made. First of all, the project is considered research and its outcome is a prototype. This means that the risks and uncertainties are usually higher than at the product development stages. Second, the project timing happens to be tight given the complexity of the task at hand. These two observations influenced the system engineering process presented in the next subsections.

### 2.2 Product development steps

This project uses the traditional "Vee" diagram to define cascading stages in the development process. While this diagram and its specific representation in Caltrans' guidelines for ITS system engineering were used as a base line, simplifications were made based on the nature of the project.

As already mentioned, this project intends to develop a prototype and not the finished product. Moreover, the research aspect entails an exploratory component that is not always compatible with the stiffness of the system engineering development process.

This led the project team to consider what in the cascading process was really of importance to the ultimate success of the research. The research will be successful if 1) the prototype demonstrates some potential safety benefits and if, as previously stated, 2) it can be handed off to the industry for widespread deployment. The system engineering process has only limited ability to realize the first part of this proposition. On the other hand, the subsequent deployment to the industry will be greatly facilitated if documentation is readily available to allow building on top of the prototype. On a side note, if the first iteration of this research meets tough challenges, it will also be much easier to track down what went wrong, whether it is the implementation or the realization that the research is not looking in the right direction.

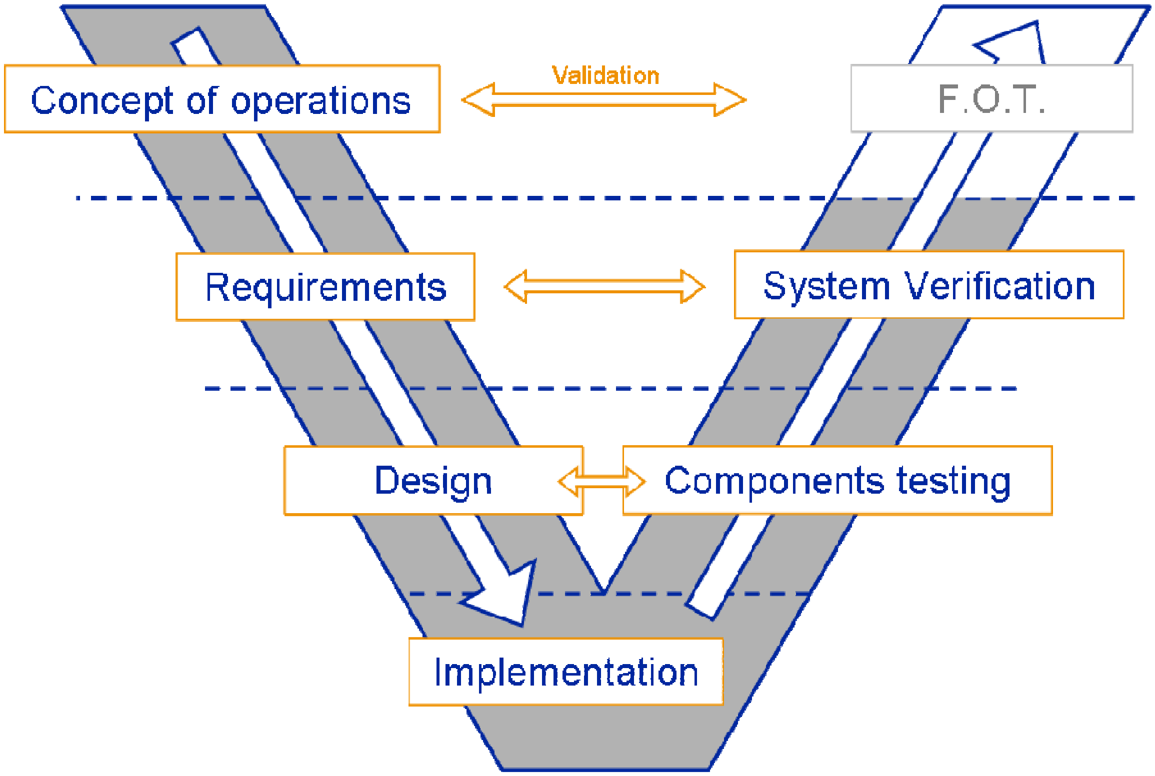
As a result, what was deemed essential to this development process is:

- A detailed concept of operations
- The system requirements
- The system design
- The verification of the system's features and attributes

On the other hand, the distinction between high-level design and detailed design, or a thorough and staged validation of each subsystem will not be documented. The outcome of this decision is that the amount of documentation will be slightly less than a formal system engineering approach would normally recommend.

With the aforementioned provisions, the system engineering process for this project will apply the framework of the Vee diagram. This means that, starting with the concept of operations, the project team will gradually define and implement the system. Subsequently, the system will be tested and verified. Figure 1 represents the overall Vee diagram for this project. Note that the Field Operational Test (FOT) is show in white. This reflects the fact that the FOT is not a part of this project, but rather a complement to it. Although its definition belongs to the current project, the project team will stop at the verification stage.

**Figure 1 - Vee Diagram**




Referring to Figure 1, the system engineering steps for this project are as follows:

- Concept of Operations: outlines how the system operates in its intended environment and justifies why it can address the problem statement;
- Requirements Definition: the requirements clarifies in more details what the system has to accomplish, and spells out the performance targets;
- System Design: the system design documents how the system is going to be built, based on requirements. It includes the system architecture and the detailed design of individual subsystems;
- Implementation: the fabrication of the system and its subsystems;
- Components Testing: tests individual subsystems to insure that they function properly and that they conform to the design;
- System Verification: overall acceptance test for the assembled system, in order to verify how well it meets the requirements.

Each of these steps defines a corresponding control gate. Control gates refer to stages in the project where stakeholders get a chance to formally review project deliverables and agree on whether or nor the project team should proceed to the next system engineering step. For this project, the control gates will take the form of review meetings with the

Caltrans project manager and the FMCSA stakeholders. Meetings may take place in person or over the phone depending on the circumstances. The project team will deliver applicable documents and other deliverables for review meetings one week before the meeting. Control gates and their corresponding meetings are tentatively scheduled in the overall work plan.

### 2.3 Sequence of implementation

A second consideration in adjusting the system engineering nominal development process was the tight timeframe allocated to the project. This essentially means that the development process cannot be linear. It should rather try to maximize the available time by conducting some of the tasks in parallel. In this area, the project team attempted to think creatively about the system engineering process. Although both a concept of operations and some clear requirements need to be formulated for this project, they will only impact part of the product design. This stems from 2 reasons: 1) the basic requirements are already known: there needs to be an onboard computer that can read sensor inputs which are relevant to safe driving behavior; 2) PATH has already successfully implemented very similar systems in the past. Based on these observations, one can say that 1/3 of the system is already known from the project team, this said without in any way limiting the range of potentialities for the prototype.

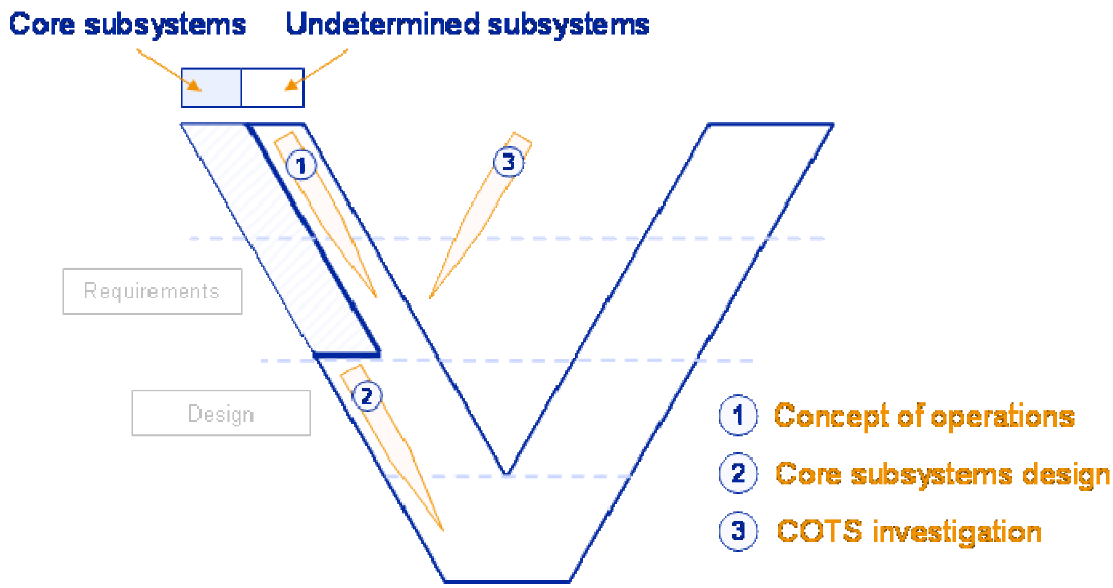
As a result, the system engineering process for this project considered a "core" of components that are known to be part of the system to be developed, regardless of the decisions made in the concept of operations. For these core subsystems only, the design can start almost immediately and funnel into implementation as needed, on a faster track than for the rest of the subsystems. This allows to spread some of the engineering resources over a longer period of time and to provide flexibility in the schedule.

Core subsystem description TBD.

Another acceleration step that was taken by the project team is an early start for the investigation of existing commercial off-the-shelf (COTS) sensors. Because most of the onboard sensors will be COTS or slight modifications thereof, and because there is not such a vast market, it is appropriate to start reviewing sensors regardless of what the requirements will say. This will essentially provide more schedule flexibility for the hardware group, freeing resources for the later stages.

The acceleration steps, namely the parallel track for the core subsystems and the early COTS investigation, is depicted in Figure 2.

**Figure 2 - Vee Diagram Acceleration**




Finally, it is to be noted that even though the FOT is not part of the present project, a task will be devoted to generating a FOT plan. Because the specifics of the FOT will be affected by multiple factors that will unfold throughout the project, the execution of the corresponding task will be kept relatively independent from the rest of the project. A major requirement of the FOT and of some of the tasks in the current project is the determination of the partner carrier. This will be tackled early in the project.

### *2.4 Engineering disciplines and integration*

This project will require the integration of multiple engineering disciplines. This section outlines these disciplines and show what their respective contributions to the project will be. In order to control the integration of these disciplines as plans are developed and changes are made, a configuration management process will be applied. This process is described in section 3.2, Technical Plans.

The OBMVS project includes the integration of five engineering specialties. The following bullet points provide a short description of each of them:

- Human factors: Human factors are the core-science of this project. Most accidents involve some kind of driver error. The system intends to warn drivers of behaviors that lead to dangerous situations, as they occur and/or through targeted feedback, which can ultimately reduce the number of crashes. Human factors will direct the concept of operations and the system requirements. As such, this discipline will be instrumental all throughout the project to insure that the requirements are well captured by other disciplines. Human factors will also specify system user interfaces if applicable.

- Hardware engineering: The project product will be comprised of several hardware subsystems, including various sensors, a computer board, and potentially some user interfaces. These subsystems will be linked together and mounted onboard a truck. The hardware engineering group will select COTS hardware subsystems, design and build additional custom subsystems as needed, design and implement an architecture to interface the subsystems, and finally install the subsystems onboard the project truck.

- Software engineering: Software engineering will be required to program the onboard computer that sits at the center of the project system. Depending on the concept of operations, software engineering may also be required to program user interfaces, whether onboard the truck or on a remote server. The software engineering group will design and implement the software subsystems.

- Data intelligence: Data intelligence refers to the set of algorithms that may be needed to process the flow of data from the selected truck sensors and assemble meaningful metrics as defined by the concept of operations. Determining these algorithms requires a good understanding of the available data and how data from different sensors can be combined together. The data intelligence group will participate in the selection of the onboard sensors, conduct extensive data analysis and design the data processing algorithms.

- Experiment design: The follow-up to this project will be a Field Operational Test intending to validate the system. The design of the FOT will be part of the research phase and is therefore included in this SEMP. The FOT design will define the experimental protocol that will be used to validate that the system has the potential to reduce accidents in a cost-effective manner. The experiment design group will lay out performance metrics that will be measured as part of the FOT, design test procedures, and develop a data analysis plan.

In addition to these five engineering specialties, two more disciplines are involved in the project:

- System engineering: System engineering is responsible for the overall prototype development process, including planning and tracking, engineering specialties integration, risk management, documentation and configuration management.

- Product deployment: The product deployment group will lay the ground for the ultimate commercialization of a product based on the outcome of this project. Their role is described in more detail in section 2.5, Product Deployment.

Table 1 shows the involvement of the various disciplines in each task of the project. Project tasks are presented in section 3. Additionally, Table 2 is a matrix indicating the specific application of the five engineering specialties through the system engineering process defined for this project. It shows how the disciplines will interact and complement each other throughout the 6 stages of the prototype development process. Note that these 6 stages correspond to tasks 2 to 7 in the project plan.

**Table 1 - Disciplines x Tasks Project Matrix**

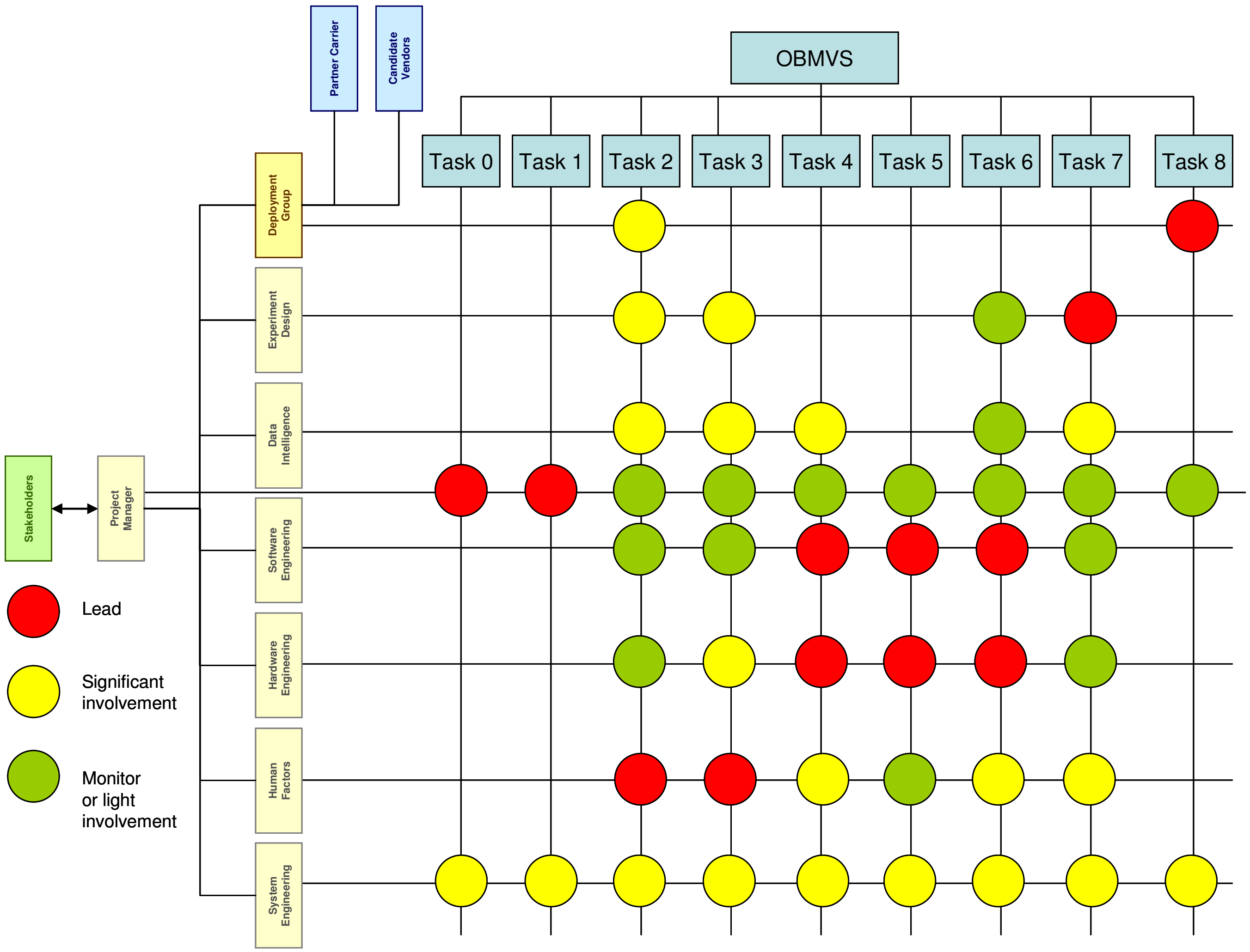


**Table 2 - Engineering Specialties Integration in the System Engineering Process**

| Stages / Disciplines | Human Factors | Hardware Engineering | Software Engineering | Data Intelligence | Experiment Design |
|---|---|---|---|---|---|
| **1. Concept of operations** | [Technical lead] - Identifies accident factors<br>- Defines safety attributes<br>- Outlines feedback to the driver and/or the carrier management | [Light involvement] - Provides inputs on feasibility within time and budget | [Light involvement] - Provides inputs on feasibility within time and budget | [Significant involvement] - Insures that safety indicators can be derived from elementary sensor inputs | [Technical lead] - Determines measures of success<br>- Designs FOT protocol |
| **2. Requirements** | [Technical lead] - Lists parameters to measure & parameters boundaries<br>- Develop application cases & specifies feedback<br>- Develop performance specifications | [Significant involvement] - Provides inputs on feasibility within time and budget<br>- Investigates existing COTS sensors and defines the feasible envelope | [Light involvement] - Provides inputs on feasibility within time and budget | [Significant involvement] - Links parameters to measure with safety indicators<br>- Participates in sensors review to verify that parameters are available | [Significant involvement] - Designs verification procedures |
| **3. System Design** | [Significant involvement] - Check overall conformity of design to requirements<br>- Participate in user interface design if any | [Technical lead] - Selects COTS sensors<br>- Designs custom sensors<br>- Designs hardware architecture<br>- Designs components mounts for truck | [Technical lead] - Designs all software products, including input reading and processing software, analysis software, and reporting and warning software | [Significant involvement] - Analyzes data stream from sensors<br>- Designs algorithms to fuse sensor inputs if needed<br>- Designs algorithms to diagnose overall data | [Not involved] |
| **4. Implementation** | [Not involved] | [Technical lead] - Builds custom sensors if any<br>- Assembles onboard computer<br>- Builds mounts for onboard sensors | [Technical lead] - Develop software subsystems | [Not involved] | [Not involved] |
| **5. Components testing** | [Significant involvement] - Participates in testing of critical human factors components<br>- Tests ergonomics of hardware and usability of software | [Technical lead] - Tests hardware subsystems (performance, reliability, ruggedness…) | [Technical lead] - Tests software subsystems (QA) | [Light involvement] - Tests algorithms implementation | [Light involvement] - Participates in components testing<br>- Gets to know the developed system |
| **6. System verification** | [Technical lead] - Verifies conformity to requirements | [Light involvement] - Assists in overall system verification | [Light involvement] - Assists in overall system verification | [Significant involvement] - Collects data from system<br>- Verifies conformity of algorithms to requirements | [Technical lead] - Applies verification procedures<br>- Collects overall experiment data |

**Legend:** Not involved | Light involvement | Significant involvement | Technical lead

### 2.5 Product deployment

The ultimate goal of this project is the deployment of a commercially available system that can reduce truck accidents. Reducing truck accidents will reduce fatality rates on the road, and can also translate into operational savings for trucking companies.

Because this project only intends to develop a prototype, deployment is one step remote. Yet, it will be examined and taken into consideration as part of the engineering decisions made during the project. This is one of the reasons why CCIT is involved in this project, and the deployment activities and how they should relate to engineering will be the responsibility of their group.

Dimensions to be examined as part of the overall deployment objective are captured by the following items:

- Quality and thoroughness of the product documentation
- Applicability of the design to a wider framework than the one of the project (alternative sensors procurement, different truck models, different drivers and company culture, different state regulations…)
- Intellectual property issues for transfer to an industry partner
- Benchmarking of the current market for truck safety products
- Tracking the assembly costs of the prototype to insure it stays within reasonable limits of what the industry typically accepts (per benchmark)

The deployment group will work with system engineering and the project manager to assess and monitor these dimensions.

## 3 Project plans

This section presents the work plan, deliverables, milestones, the technical plans, and the project management and reporting structure.

### 3.1 Scope of work

The overall scope of this project is to conceptualize, design, implement and test a prototype system to monitor truck driving safety in real-time and provide diagnostics. Additionally, a framework will be developed to evaluate the prototype in an operational environment. This requires finding a partner carrier.

The scope of work is made up of nine tasks, including a general management and reporting task (task 0). The nine project tasks are as follows:

<u>Task 0.</u> Management and Reporting

Project Management and Reporting includes all those activities related to normal project management as well as monitoring delivery of all required deliverable items and reports.

PATH will also prepare research papers and presentations at academic and technical symposiums and conferences as appropriate.

Task 1. Planning

Project planning refers to the development of the various plans needed to successfully complete the project. For the most part, this is covered by the System Engineering Management Plan. Additionally, this task includes the determination of the partner carrier and the deployment-related activities.

Task 2. Develop Concept of Operations

In this task, the research team will assess primary safety indicators and derive the concept of operations, in coordination with the project stakeholders and the partner carrier.

Task 3. Develop Requirements

In this task, the project team will develop the system requirements, including a list of inputs to be measured, the type of feedback that the system will provide, and performance specifications. The system requirements will feature application cases. Along with the requirements, a system verification plan will be developed.

Task 4. Develop System Architecture and Design

This task will define all the subsystems and how they interface with one another. The design provides all the data algorithms and the detailed hardware, software and user interfaces specifications that will be used to implement the system. As part of this task, the team will also develop test plans aimed to evaluate individual subsystems following their implementation.

Since this project is primarily using Commercial-Off-The-Shelf (COTS) for truck sensors, a number of components testing plans will use information provided by the COTS vendors.

Task 5. Implementation

Implementation consists of the development of an onboard monitoring suite to include the procurement of the COTS hardware, and fabrication of any custom hardware.

Task 6. Components Testing

This task includes testing each subsystem against the appropriate level of requirements. Each software module will be individually tested to demonstrate proper operation. Individual hardware components will be similarly tested.

Task 7. System Verification

The final task for this phase of the project is to demonstrate the operation of the system, both at low speeds and finally at high speeds, using a controlled full-scale experiment with one fully outfitted tractor with on-board monitoring suite as final verification to show the developed product meets requirements.

Note that this phase of the project ends with an acceptance test showing the system meets requirements (Verification), but does not extend into Validation (which would show the product meets the user needs as defined in the Concept of Operations). Validation of the system will be accomplished when the FOT evaluation is completed.

Task 8. Develop Field Operational Test

In this task, the project team will define the system performance metrics, develop evaluation procedures and prepare a framework for analyzing FOT data.

The deliverables for the project are shown in Table 3, along with the corresponding tasks.

**Table 3 - Project Deliverables**

| Task / Index | Deliverable |
|---|---|
| 0ABCD | Quarterly Progress Reports |
| 0E | Project Final Report |
| 1A | System Engineering Management Plan |
| 2A | Concept of Operations (ConOps) Document |
| 3A | System Requirements Document |
| 3B | System Verification Plan |
| 4A | System Design Document, including COTS specifications and Testing Procedures |
| 5A | Developed Systems (Hardware and Software) |
| 6A | Components Testing Report |
| 7A | Prototype System Acceptance Test Report |
| 8A | Field Operational Test Plan |

## *3.2 Technical plans*

### 3.2.1 Integration plan

The Integration plan indicates when and how system components will be assembled together as part of the system as a whole. It spells out the sequence of integration, the procedures and criteria involved in the integration of specific components to the system and whether the integration takes place on a test bench first or directly onboard the project truck. The integration plan will be completed as part of the system design.

| **Integration Plan** | |
|---|---|
| **INPUT**<br>*Sources of Information* | • Hardware Development Plan |
| **PROCESS**<br>*Key Activities* | • Review RFP/Work Plan and defined Task 4 Objectives<br>• Review the Hardware Development Plan<br>• Contact with vehicle manufacturer and maintenance personnel for vehicle functioning and build information<br>• Envision methods that would integrate the hardware in the vehicle |
| **OUTPUT**<br>*Results from Process* | • This Integration Plan<br>• Detailed Integration Plan |
| **Tools** | • Vehicle maintenance and technical manuals<br>• Microsoft Word for writing the plan |
| **Review** | • Draft plan will be submitted to customer and broader team for review. Written comments will be addressed and incorporated and customer approval will be received before moving to the next step in the process. |

### 3.2.2 Configuration management plan

Configuration management is a tool designed to document and track changes made to the system and its components, whether it is features, hardware design, software versions etc… Once the system design is known, the system engineering team will set up and apply a configuration management process. The configuration management process will use an electronic document as a repository that will be accessible by each team member. This electronic document will likely be a MS Excel spreadsheet that will be organized in sections corresponding to the design areas. The configuration management spreadsheet will be a live document meant to be modified on the fly. Every month, the live version will be saved into an archive for future reference. This will establish a track of past configurations to document the prototype development.

| **Configuration Management Plan** |
|---|

| | |
|---|---|
| **INPUT**<br>*Sources of Information* | • System Engineering Management Plan<br>• System Requirements Document<br>• System Design Documents<br>• Bi-Monthly meetings |
| **PROCESS**<br>*Key Activities* | • Establish key characteristics of the system being developed (safety attributes to monitor, data metrics, hardware and software requirements, physical characteristics of the system…)<br>• Map characteristics into a numbered list of qualitative and quantitative items.<br>• Create a flexible spreadsheet structure to host these items.<br>• Instruct the team on how to read and edit the spreadsheet.<br>• Make the spreadsheet available on the project's FTP site.<br>• Status accounting: every month, integrate inputs from the team and freeze the latest version for archiving. Inputs will be collected informally on a continuous basis and reviewed with the whole team before being frozen.<br>• Audit changes: major configuration changes are fed back to the project's Change Control Board (CCB), comprising the project system engineering team, management team and sponsors for approval. |
| **OUTPUT**<br>*Results from Process* | • Configuration management spreadsheet – initial baseline and monthly frozen versions.<br>• The Change Control Board<br>• A trail of past configurations and configuration changes, archived on a monthly basis.<br>• Audit results |
| **Tools** | • Microsoft Excel |
| **Review** | • Initial spreadsheet will be reviewed by project management and sponsors for process approval.<br>• Subsequent versions will be available for review on a continuous basis. |

### 3.2.3 Verification plan

The verification plan spells out the procedures and measurements that will be employed to verify how well the built prototype meets the system requirements. The verification plan is a deliverable of Task 3, System Requirements.

| **Verification Plan** | |
|---|---|
| **INPUT**<br>*Sources of Information* | • Requirements Document |

| | |
|---|---|
| **PROCESS**<br>*Key Activities* | • Review RFP/Work Plan and define Task 3.5 Objectives<br>• Review the Requirements Document<br>• Envision tests that would verify system meets the requirements. |
| **OUTPUT**<br>*Results from Process* | • This verification plan<br>• A detailed verification plan |
| **Tools** | • The developed prototype system will be used to verify system performance<br>• Other instrumented vehicles may be used in the verification testing<br>• Matlab and/or other engineering software will be used to review and analyze raw and reduced data<br>• Microsoft Word and Excel will be used for data management and report writing |
| **Review** | • Draft plan will be submitted to customer and broader team for review. Written comments will be addressed and incorporated and customer approval will be received before moving to the next step in the process. |

### 3.2.4 Risk management plan

The risk management plan identifies individual project risks and indicates mitigation strategies. The risk management plan will be started at the beginning of the project and be augmented as necessary until the system design is completed. It will be modeled after the *FAA Programmatic Risk Analysis Approach.*

| **Risk Management Plan** | |
|---|---|
| **INPUT**<br>*Sources of Information* | • System Engineering Management Plan<br>• System Requirements Document<br>• System Design Documents<br>• Bi-Monthly meetings |

| | |
|---|---|
| **PROCESS**<br>*Key Activities* | • Identify risks<br>    o Begin with risks identified at onset of project and documented in kickoff<br>        1. Obtaining carrier partner<br>        2. OBM implementation (hardware and software)<br>        3. High quantity of reporting<br>• Analyze risks and rank consequences<br>*Likelihood*<br>    o A: Not likely<br>    o B: Low likelihood<br>    o C: Likely<br>    o D: Highly Likely<br>    o E: Near Certainy<br>*Consequence*<br>    o Level 1: Minimal impact<br>    o Level 2: Minor performance shortfall, same approach retained<br>    o Level 3: Moderate performance shortfall, alternatives available<br>    o Level 4: Unacceptable performance, but alternatives available<br>    o Level 5: Unacceptable performance, and no alternatives exist<br><br>Focus will be where *likelihood* x *consequence* is high.<br><br>• Create a flexible spreadsheet structure to monitor and track risks, particularly where aforementioned product is high.<br>• At each bi-weekly, address all risks with focus on higher level risks; select risk mitigation option<br>• During project execution, implement risk mitigation decisions and plan |
| | • Awareness and buy-in on risks<br>• Tracking of risks<br>• Risk mitigation plan |
| **Tools** | • Microsoft Excel |
| **Review** | • Bi-weekly with project team, to include Caltrans management |

### 3.2.5 Plan for Concept of Operations

This Task 2 effort is the marriage of a literature review, stakeholder feedback, and technical inputs, resulting in the concept of operations document deliverable. As shown in the following table, there are four main tasks which will provide input to concept of operations document. First, there is a COTS survey. Second there is an identification of causal factors in truck crashes. Third, there is a literature review on various specific and relevant Human Factors related issues, and finally, there is stakeholder input gathered during interviews and ride-alongs.

| **Concept of Operations Plan** | |
|---|---|
| **INPUT**<br>*Sources of Information* | • Product literature for COTS onboard monitoring systems<br>• Reports published by the Center for National Truck and Bus Statistics<br>• Peer-reviewed academic literature<br>• Stakeholder input |
| **PROCESS**<br>*Key Activities* | • Survey the market for COTS monitoring systems documenting what parameters the system monitors and how feedback is given to the drivers.<br>• Review the literature published by the Center for National Truck and Bus Statistics to identify causal factors in the truck crashes<br>• Review the literature that has been published on the topic of onboard monitoring and driver feedback<br>• Review the literature on various driving performance measures such as speed, lane position, headway, and fatigue with intent to determine how to convert the monitored data into a measure of driving performance<br>• Perform a task analysis during a ride-along with a stakeholder partner<br>• Perform a management interview with a stakeholder partner<br>• Develop application cases for the concept of operations document<br>• Develop driver feedback concepts for the concept of operations document |
| **OUTPUT**<br>*Results from Process* | • Onboard Monitoring Concept of Operations Document<br>o Provides a review of relevant literature<br>o Provides a survey of COTS monitoring systems<br>o Provides a draft concept of what parameters should be monitored<br>o Provides a rationale for how to use the monitored parameters to make a statement about driving performance<br>o Provides a draft concept of how feedback should be provided to the driver for each monitored parameter |
| **Tools** | • Access to Science Direct, Ingenta Connect, and the UCB Library<br>• Adobe Acrobat Reader (to read and print on-line literature)<br>• Microsoft Word (for document development)<br>• Video Camera (for recording interviews and ride-alongs) |
| **Review** | • Periodic presentations at the bi-weekly meetings will be provided to review the findings of the COTS survey, literature review, and stakeholder inputs. |

### 3.2.6 Hardware development plan

The hardware development plan will outline the implementation of required hardware components for the system, such as the tools to be employed and the distribution of tasks among the team. It will include test plans for the hardware components. The hardware development plan will be finalized when the hardware design is complete.

| **Hardware Development Plan** | |
|---|---|
| **INPUT**<br>*Sources of Information* | • Requirements Document |
| **PROCESS**<br>*Key Activities* | • Review RFP/Work Plan and defined Task 4 Objectives<br>• Review the Requirements Document<br>• Review Availability of COTS sensors and equipment |
| **OUTPUT**<br>*Results from Process* | • This Hardware Development plan<br>• A detailed hardware development plan |
| **Tools** | • Microsoft Word (for document development) |
| **Review** | • Draft plan will be submitted to customer and broader team for review. Written comments will be addressed and incorporated and customer approval will be received before moving to the next step in the process. |

### 3.2.7 Software development plan

Software development will be required to interface COTS hardware and software to the onboard data gathering computer that sits at the center of the project system and to do any data filtering or archiving services required by the data intelligence operations. Depending on the concept of operations, software engineering may also be required to program user interfaces for safety systems, based on data intelligence analysis, whether on board the truck or on a remote server.

| **Software Development Plan** | |
|---|---|
| **INPUT**<br>*Sources of Information* | • Concept of operations plan and requirements document.<br>• Hardware development plan and COTS system documentation.<br>• Data intelligence plan and list of required data elements.<br>• If user interfaces are part of the requirements, human factors input specification for the characteristics of the interfaces. |

| | |
|---|---|
| **PROCESS**<br>*Key Activities* | • Identify major software subsystems and capabilities required of each.<br>• Define and document data and control interfaces between hardware and software components.<br>• Develop prototype software to test capabilities of COTS hardware and software.<br>• Revise software subsystem capabilities and interface requirements based on results of COTS system testing.<br>• Evolve prototype COTS testing software into a hardware and components test suite that can be used to check integrity of system<br>• Write prototype data gathering software and collect initial data sets.<br>• Add capabilities or improve performance as required for correct operation of safety system, based on data intelligence analysis carried out on initial data sets.<br>• Develop regression tests to ensure integrity of software development as capabilities are added.<br>• With human factors group, develop and carry out tests of any user ineterfaces. Iterate software process as required to address deficiencies identified by testing.<br>• Document software and testing procedures. |
| **OUTPUT**<br>*Results from Process* | • Software for data gathering and safety systems.<br>• Test software for system components and software integrity.<br>• Documentation for software and testing procedures. |
| **Tools** | • Real-time operating system for data gathering – QNX6 or (possibly) a real-time version of Linux.<br>• C programming language and Unix scripting and filtering tools.<br>• Open-source package *doxygen* for automatic generation of software documentation in .pdf or .html format.<br>• User interface development package may be needed. |
| **Review** | • Quarterly reports will be submitted to customer and broader team for review. A web page will be maintained containing current software documentation. |

### 3.2.8 Data Intelligence plan

The data intelligence plan will outline the scope and extent of data intelligence tasks for this project. Data intelligence will be concerned with the safety measurements defined by the system requirements and how to assemble these measurements from available sensor inputs. The plan will indicate how data will be collected and analyzed so that algorithms can be properly calibrated, what tools will be used, and how the adherence of the system data processing algorithms to the requirements will be measured. The data intelligence plan will be produced once the requirements are completed.

The objective of the project is for on board monitoring with some feedback reminding (warning) to the driver, which is to be determined with the iterative development of the project. Sensor specification, detection, tracking, information from J-1939 Bus and data fusion will depend on the system performance requirement. Some of the measures will be processed in real-time to provide feedback to the driver. Other data will be collected for after processing to analyze driver's behavior related to safety.

| **Data Intelligence Development Plan** | |
|---|---|
| **INPUT**<br>*Sources of Information* | • List of parameters to be monitored<br>• List of sensors<br>• Description of data from sensors<br>• Requirement of feedback to the driver<br>• Requirement of data logging for after processing<br>• Dangerous situation in operation<br>• Previous work in Warning System Study including threat assessment |
| **PROCESS**<br>*Key Activities* | • According to the requirement to develop tracking and sensor fusion algorithm<br>• According to the specification, development and Implementation of threat assessment algorithm for heavy-duty truck for longitudinal motion<br>• With human factors group, develop warning scenarios and feedback if necesary<br>• System integration of on board signal processing, monitoring of driver's operation regulation violation, and threat assessment<br>• Field testing and data analysis<br>• Data off-line processing<br>• System refining |
| **OUTPUT**<br>*Results from Process* | • Multiple frontal target detection and tracking using radar and lidar<br>• An integrated system for real-time signal processing , monitoring of driver's operation regulation violation, threat assessment and warning<br>• Documentation for algorithm, software and testing procedures |
| **Tools** | • Real-time operating system for data processing such as QNX. 6.0<br>• C programming language<br>• Matlab packages |
| **Review** | • Quarterly reports will be submitted to customer and broader team for review.<br>• Customer's feedback will be incorporated in system tuning and refining.<br>• A web page will be maintained containing current algorithm, software, and system documentation. |

Table 8 indicates who in the team is responsible for each plan and when it should be completed.

**Table 4 - Technical Plans Responsibilities and Schedule**

| Technical Plan | Who? | When? |
|---|---|---|
| Integration Plan | Scott | Task 4 |
| Configuration Management Plan | JD | Task 3 |
| Verification Plan | Scott | Task 3 |
| Risks Management Plan | Jim | Tasks 1-4 |
| Causal Factors Plan | Joanne & Christopher | Task 1 |
| Hardware Development Plan | Scott | Task 4 |
| Software Development Plan | Sue | Task 4 |
| Data Intelligence Plan | Xiao-Yun | Task 3 |

## *3.3 Team, resources and organization*

### 3.3.1 Staff and resources

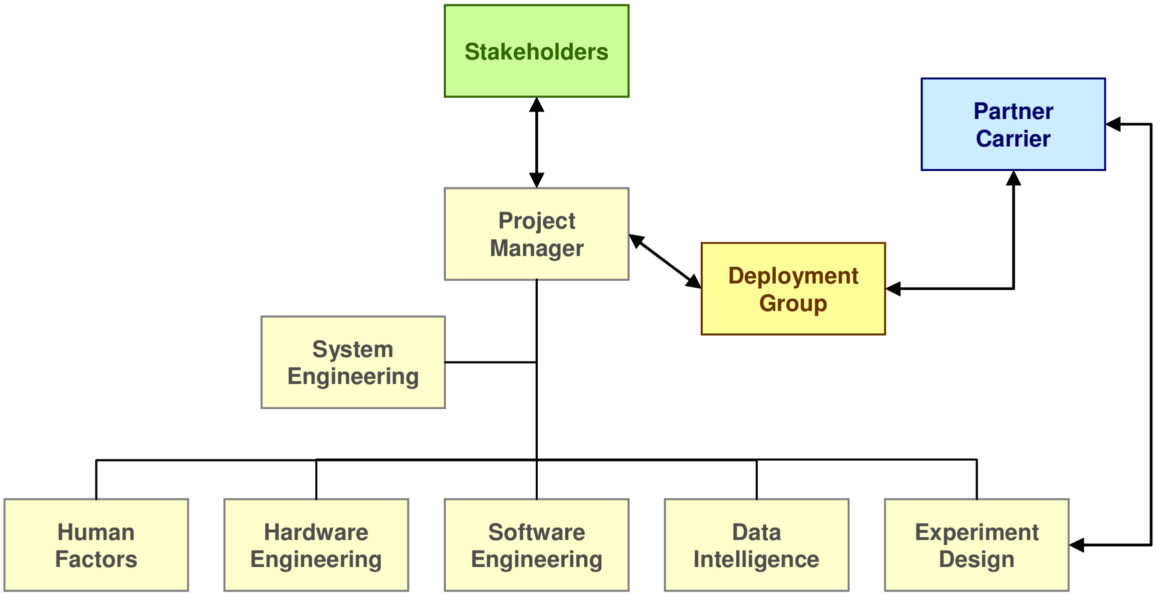
PATH is the primary contractor for this project. The project team comprises PATH staff members as well as staff from other Transportation Research Centers at the University of California, Berkeley. In addition, a professional system engineer was hired on a subcontract.

### 3.3.2 Organization

The project team is organized under the responsibility of the project manager. For each engineering discipline, a group leader is designated and bears responsibility for carrying out specific tasks, providing deliverables, and acting as a coordinator for their discipline. This means reporting to the project team as a whole and being a liaison with other disciplines.

Figure 3 represents the overall organization chart for this project. It includes the yet-to-be-determined partner carrier. Tan boxes indicate the groups that specifically belong to the project.

**Figure 3 - Project organizational chart**




Throughout the project, meetings will be held to allow updates within the project team. The nominal frequency of team-wide meetings is one meeting every other week. Specialty group meet informally on an ad-hoc basis.

**New Risks**

| | *Levels of Risk Likelihood A - E* | | | | | |
|---|---|---|---|---|---|---|
| | A: Not Likely | B: Low likelihood | C: Likely | D: Highly Likely | E: Near Certainty | Comment |
| *Consequences 1 - 5* | | | | | | |
| Level 1: Minimal Impact | | | | | | |
| Level 2: Minor performance shortfall, same approach retained. | | | | | | |
| Level 3: Moderate performance shortfall, alternatives available. | | | | | | |
| Level 4: Unacceptable performance, but alternatives available. | | | | | | |
| Level 5: Unacceptable performance, and no alternatives exist. | | | | | | |
| Comment | | | | | | |

**Obtain Carrier Partner**

| | *Levels of Risk Likelihood A - E* | | | |
|---|---|---|---|---|
| | A: Not Likely | B: Low likelihood | C: Likely | D: Highly Likely |
| *Consequences 1 - 5* | | | | |
| Level 1: Minimal Impact | | | | |
| Level 2: Minor performance shortfall, same approach retained. | | | | |
| Level 3: Moderate performance shortfall, alternatives available. | | | | |
| Level 4: Unacceptable performance, but alternatives available. | Smart & Final (S&F) | | | |
| Level 5: Unacceptable performance, and no alternatives exist. | | | | |
| Mitigations | 1. Develop and sign MOA 2. Frequent communication with S&F | | | |

| | |
|---|---|
| E: Near Certainty | Mitigations |
| | |
| | |
| | Create stakeholder group -- Advisory Panel |
| | |
| | |

**OBM implementation (hardware and software)**

| | | | | |
|---|---|---|---|---|
| | *Levels of Risk Likelihood A - E* | | | |
| | A: Not Likely | B: Low likelihood | C: Likely | D: Highly Likely |
| *Consequences 1 - 5* | | | | |
| Level 1: Minimal Impact | | | | |
| Level 2: Minor performance shortfall, same approach retained. | | | | |
| Level 3: Moderate performance shortfall, alternatives available. | | | Timeline between requirements completion and h/w and s/w completion very short | |
| Level 4: Unacceptable performance, but alternatives available. | | | | |
| Level 5: Unacceptable performance, and no alternatives exist. | | | | |
| Mitigations | | | If risk increases to Level 4, ask customer for NCE | |

| | | |
|---|---|---|
| | | |
| E: Near Certainty | Mitigations | |
| | | |
| | | |
| | | |
| | Begin integrating obvious h/w and s/w immediately after definition of ConOps | |
| | | |
| | | |
| | | |

**High quantity of reporting**

| | | Levels of Risk Likelihood A - E | | | |
|---|---|---|---|---|---|
| | | A: Not Likely | B: Low likelihood | C: Likely | D: Highly Likely |
| *Consequences 1 - 5* | | | | | |
| Level 1: Minimal Impact | | | | | |
| Level 2: Minor performance shortfall, same approach retained. | | | | | |
| Level 3: Moderate performance shortfall, alternatives available. | | | | | Project reporting/documentation level high due to systems engineering process; higher than PATH experience. |
| Level 4: Unacceptable performance, but alternatives available. | | | | | |
| Level 5: Unacceptable performance, and no alternatives exist. | | | | | |
| Mitigations | | | | | Caltrans customer to approve SEMP and revised SOW? |

| E: Near Certainty | Mitigations | |
|---|---|---|
| | | |
| | | |
| | | |
| | 1. Hire ASE Consultants to assist. 2. Obtain CCIT (JD) to assist. 3. Compress some requirements with SEMP and revised SOW. | |
| | | |
| | | |
| | | |

Interim Project Report March 2006

# ONBOARD MONITORING AND REPORTING FOR COMMERCIAL MOTOR VEHICLE SAFETY:

# DELINEATING CAUSAL FACTORS

*California PATH*
Christopher Nowakowski

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# 1. OVERVIEW

## 1.1. Preface

This interim project report has been prepared to provide background on the topic of onboard driver monitoring systems for use in commercial heavy vehicles. The purpose of this project was to develop a concept of operations and a required sensor suite for an ideal driver monitoring system which would help to improve fleet safety.

This report covers two topics. First, it reviews the research that has been published on the topic of onboard driver monitoring systems, as well as reviewing the various commercial-off-the-shelf (COTS) driver monitoring systems that were being manufactured at the time of this report. Second, this report reviews some of the recent literature on the topic of delineating causal factors for large truck crashes.

A successful driver monitoring system should ideally monitor "unsafe" driving behaviors, which might be defined as any behavior that can be shown to be a precursor to increased crash risk. Thus, to understand what behaviors are unsafe, we must first understand what factors "cause" or lead to crashes involving large trucks. As discussed throughout this literature review, this is no easy task, and ultimately, the research to definitively answer this question is still ongoing. However, the delineation of truck crash causal factors is still a key element required to create a concept of operations for an onboard driver monitoring system, even if the research reporting the casual factors is still preliminary.

## 1.2. Introduction

Each year over 450,000 large trucks are involved in crashes resulting in about 5000 fatalities and 120,000 injuries according to the most recent compilation of traffic safety facts released by the National Highway Traffic Safety Administration (NHTSA). Overall, crashes involving large trucks comprise 4.1 percent of all crashes, but they also contribute to 12 percent of all fatalities (or one out of every nine). Furthermore, more than 85 percent of the time, the fatality was not an occupant of the truck (NHTSA, 2003).

The University of Michigan Transportation Research Institute (UMTRI) publishes a yearly, in-depth analysis of trucks involved in fatal accidents. On the surface, these studies reveal nothing extraordinary about the accident conditions when large trucks are involved. Nearly two-thirds of the crashes occur in rural areas with almost 55 percent occurring on a state or U.S. highway and 25 percent occurring on interstates. Almost two-thirds of the fatalities occurred during daylight and over 80 percent occurred on dry roads during normal weather (Matteson, Blower, and Woodrooffe, 2004).

The there are a few statistics that do stand out about the drivers of large trucks involved in crashes. First, 96 percent of the drivers of large trucks involved in fatal crashes were male, which is probably not surprising given the distribution of men and women in the profession. Fatigue, although often discussed and highly researched in long haul trucking, was only reported as a factor in 1.5 percent of the fatal crashes (Matteson, Blower, and Woodrooffe, 2004). Finally, only about 1 percent of the truck drivers involved in fatal crashes had a blood alcohol concentration greater than 0.08 g/dl (the legal limit in many states), whereas 22 percent of the drivers of cars and SUVs involved in fatal crashes were reported as intoxicated at the time of the crash (NHTSA, 2003).

Overall, the crash statistics reveal nothing extraordinary about the types of crashes involving trucks and truck drivers, other than the fact that fatalities occur more often when large trucks are involved, which is not surprising given the large disparity in size and mass between cars and trucks. Furthermore, most of the recent research aimed at understanding large truck crash causation has revealed that the actions of the drivers of the cars contribute more often to the crash than do those of the truck driver (Kostyniuk, Streff, and Zakrajsek, 2002; Stuster ,1999; and Blower, 1998). This sentiment has also been repeated by truck drivers themselves such as during the focus groups conducted by Roetting, Huang, and McDevitt (2003). However, this is not to say that truck drivers are always completely without fault, or that driver monitoring and feedback would provide no benefits.

In fact, driver monitoring and feedback may prove to be extremely beneficial, especially for younger or novice truck drivers. It has been shown that novice drivers are overly represented in crash statistics, and that novice truck drivers who were involved in crashes were more likely to frequently exhibit excess speed or overly aggressive driving such as following too closely. They were also more likely to exhibit signs of possible attentional overload or loss of vehicle control (Blower, 1996). All of these behaviors could be candidates for driver monitoring and feedback.

Recent analysis of instrumented truck studies (Knipling 2005) has also given weight to the notion that individual differences and behaviors play a large role in crash risk. According to surveys, fleet managers often estimate that their worst 10 percent of drivers account for up to 50 percent of their fleet risk, and this estimate was supported in a critical incident analysis of the instrumented vehicles. In this study the worst 6 drivers, accounting for only 12 percent of the driving time, were responsible for 38 percent of the critical incidents. In contrast, the best 25 drivers, accounting for 63 percent of the driving time, were only responsible for 16 percent of the critical incidents. Onboard driver monitoring and feedback may be one way to objectively identify high risk drivers, and help them to curb risky driving behavior.

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## 2. ONBOARD MONITORING BACKGROUND

### 2.1. Driver Monitoring in the Context of the Behavior-Based Safety Approach

The concept of operator (driver) monitoring is neither new, nor limited specifically to the trucking industry. Sherry (2001) identified and compared operator monitoring systems used in the maritime, air freight, motor carrier, and rail industries. A more recent paper (Lotan and Toledo, 2005) discussed a pilot program in Israel which would provide driver monitoring and feedback for teen drivers.

The general case for truck driver monitoring in the trucking industry has already been made through research sponsored by the Federal Motor Carrier Safety Administration (FMCSA) and is best summarized in a technical brief (Behavioral Science and Technology, Inc., 2000). In its most simplistic form, the behavior-based safety approach is a method for improving safety, by which behaviors critical to safety are identified and monitored. Safe behavior is rewarded and unsafe behavior is discouraged and improved upon, thereby proactively improving overall safety.

While strict driver training programs, vehicle safety inspections, and the constant monitoring of crash statistics have all been means for monitoring safety in the past, the advent of inexpensive sensing technologies has made possible the continuous monitoring speed, headway, and other driving parameters. This new technology provides the fundamentals to enable a true behavior-based safety approach. Implementing an onboard driver-monitoring behavior-based safety approach requires four steps:

1. Identify behaviors which may be precursors to increased crash rates.
2. Determine cost-effective ways to monitor safe and unsafe behaviors.
3. Determine the best way to provide the driver with feedback which rewards safe behavior and discourages unsafe behavior.
4. Establish management and driver acceptance to the program.

### 2.2. Driver Monitoring Research Review

There is much literature devoted to the many issues surrounding truck and truck driving safety, all of which can be both relevant and tangential to the concept of onboard driver monitoring, and much of that literature is discussed throughout the various sections of this report. However, there have only been about four major published studies which have specifically focused on the acceptance of onboard driver monitoring systems in the trucking industry. In the first study, Sherry (2001) interviewed both management and operators in the maritime, air freight, motor carrier, and rail industries. At the time, many of the onboard monitoring COTS devices reviewed later in this report were in existence and in use by the companies he interviewed. However, management acceptance of onboard monitoring was mostly concentrated around the issues of reducing engine idle time and fuel consumption or accident/event recording. Most management incentives based on the monitoring and feedback devices were given for reducing engine idle time.

From the driver interviews conducted in this first study, it was reported that 42 percent of the drivers would have no problems with a driver monitoring system, but almost 58 percent felt that the in-vehicle monitoring systems had been used to unfairly discipline drivers. Drivers were more accepting of systems that included some sort of collision avoidance system or provided additional tangible benefits, such as reducing paperwork and logging requirements. It was also reported that driver perceived as "good" drivers were more positive and accepting towards the monitoring systems than were drivers that were considered more problematic. Summarizing from interviews across industries, Sherry (2001) concluded that several factors (outlined in Table 1) were frequently cited in support of or against operator monitoring systems.

Table 1. Factors Influencing Onboard Monitoring Acceptance.

| Positive Influences on Acceptance | Negative Influences on Acceptance |
|---|---|
| Improved safety (if the technology lives up to its promise). | Fear of embarrassment or self-consciousness at being monitored all the time. |
| Liability protection (such as when the driver is not at fault for a crash). | Fear of liability or unfair accountability on the part of drivers such as being determined as responsible for a crash. |
| Efficiency (such as reducing paperwork). | Concern that the monitoring parameters are not indicators of safety. |
| Monetary incentives. | Misuse of the collected data. |

In the second reviewed study, Knipling, Hickman, and Bergoffen (2003) found support for driver monitoring among nearly 33 percent of trucking industry safety managers. In their survey, 36 percent of the respondents reported using some form of driver monitoring system with management review and feedback, and 33 percent of the respondents ranked driver monitoring and feedback as one of their "Top Five" choices for solutions to help improve safety. Interestingly, when given the option of driver monitoring without management review (thus insuring driver privacy), only 9 percent of the safety managers ranked this option in their "Top Five" and the option fell overall to last place (out of 28 solutions). Most industry experts and carrier safety managers seemed to agree that driver monitoring without management review would be ineffective.

The final two studies, Roetting, Huang, and McDevitt (2003 and 2005), extensively examined the topic of truck driver monitoring and feedback from the driver's perspective. In the 2003 study, a total of 66 long and short haul drivers, supervisors/managers, and insurance industry safety professionals participated in 9 focus groups. These focus groups reported similar opinions as those described above. Drivers generally felt that monitoring could have potential safety benefits and possibly vindicate the driver in the even of an incident or crash. However, privacy concerns and mistrust over the use of data were also voiced. Drivers were also concerned that feedback would be primarily negative and lead to programs focused on punishments, as opposed to incentives which reward good driving behavior.

The 2005 study surveyed 239 long and short haul drivers throughout 40 states and Canada. Drivers were generally positive towards the concept of feedback with less than half of the drivers surveyed (42 percent) responding that they were currently getting adequate feedback on their driving. Similar to the earlier focus groups, more than half the of the drivers (59 percent) felt that positive feedback would be more useful than negative feedback, and 56 percent felt that the greatest potential benefit of in-vehicle monitoring was defending the driver in the event of a crash. Unsurprisingly, the greatest concern found in the survey was over the issue of privacy. Over two-thirds or 65 percent of the survey respondents were concerned with the possibility that the data collected by the onboard monitoring system might be misused.

All of the studies outlined above basically came to the same conclusions. Truck drivers were not universally opposed to the concept of onboard monitoring and feedback, and the issues surrounding privacy and misuse of the data being collected were of primary concern. The studies all also tended to reveal that acceptance was a function of perceived benefit. The more benefit the drivers saw in the individual system, the more positive they were towards accepting the overall concept of onboard monitoring.

## 2.3. Onboard Monitoring COTS Review

### *2.3.1. Overview*

A search for commercial off-the-shelf (COTS) onboard truck driver monitoring systems turned up six major manufacturers: XATA, Delphi, Accident Prevention Plus, Cadec, QualCOMM, and DriveCam. These companies have been releasing on-board monitoring (OBM) products since as early as 2000. Two relative newcomers to the field of driver monitoring are AllTrackUSA and DriveDiagnostics. AllTrackUSA makes the Audio Monitor specifically marketed towards teen drivers, and DriveDiagnostics is an Israeli start-up with plans to make both a teen driver monitor and a fleet version.

The features promoted in OBM products include real-time location, delivery status, fuel performance, and driver logs. In general, they emphasize savings on fleet operations and maintenance costs. An overview of a typical onboard driver monitoring system is shown in Figure 1. The OBM system generally consists of three major components: sensors, a processing unit, and feedback devices. The most commonly-used sensors include the speedometer, tachometer, odometer, throttle angle encoder, GPS receiver, accelerometer, and steering encoder.

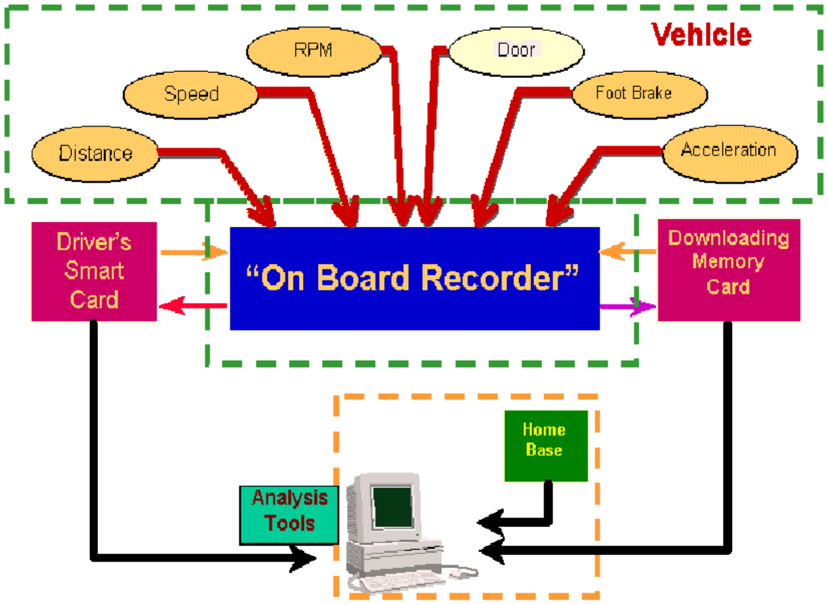


Figure 1. Typical OBM System[1]

By employing these sensors, the COTS systems measure the driver performance by monitoring signal use, position, speed, acceleration, and vehicle mechanical states, e.g. engine rpm, throttle angle, brake pressure, and so on. All these systems can be installed in a vehicle easily. Most of them also provide advanced driver identification system to avoid unauthorized use of the vehicle, but, there are some basic feature differences between systems as illustrated in Table 2.

Feedback can be provided to the driver either in real-time or after the data has been downloaded and analyzed. Real-time feedback is typically provided to the drivers through displays or speakers. Table 3 compares the feedback methods employed across systems.

[1] This figure and the information on the Accident Prevention Plus AP+ series products were from the NHTSA website at the following URL: http://www-nrd.nhtsa.dot.gov/edr-site/uploads/accident_prevention_plus.pdf

Table 2. Basic feature comparison among these products.

| Company | Features | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Preventative maintenance monitoring | Event recording using camcorder | Remote deceleration and shutdown | Real-time asset tracking | GPS-based "geo-fencing" | Driver identification | Trailer Door security | Wireless |
| XATA | × | | | × | | × | | |
| Delphi | × | | × | × | × | × | × | |
| APPlus | | | | | | × | | |
| Cadec | | | | | × | | × | × |
| QualCOMM | | | | × | | | | × |
| DriveCAM | | × | | | | × | | |
| AllTrackUSA | | | | | | | | |
| DriveDiagnostics | × | | | × | | × | | × |

Table 3. Comparison chart of feedback approaches among these products.

| Company | Feedback Device | | |
|---|---|---|---|
| | Text messaging system | Audible and visual warnings | Offline processing |
| XATA | × | | |
| Delphi | × | | |
| APPlus | | | × |
| Cadec | × | × | |
| QualCOMM | × | | |
| DriveCAM | | | × |
| AllTrackUSA | | × | × |
| DriveDiagnostics | | | × |
| | | | |

### *2.3.2. <u>XATA</u>*

XATA's OBM systems is primarily advertised for fleet maintenance, driver productivity, fuel economy, and safety and security concerns. The functions provided by this system include: (1) preventative maintenance monitoring, (2) onboard electronic logs, (3) real-time asset tracking, (4) monitor speeds, rapid stops or diagnostic warnings, (5) reconstruct accidents with Black Box data, (6) two-way driver messaging, and (7) electronic safety monitoring. Their systems incorporate GPS, speedometer, tachometer, odometer, fuel rate sensor, throttle position, braking (on/off only), clutch (on/off only). One advantage of the two-way messaging system is that the fleet manager can instantly communicate with the driver.

### *2.3.3. <u>Delphi's TruckSecure</u>*

Delphi's TruckSecure system is a fleet management tool that is advertises as a means to reduce the possibility of cargo trucks being used to threaten homeland security. The functions provided by this system include: (1) GPS-based positioning, routing, guidance, and "geo-fencing", (2) asset tracking, maintenance, and productivity, (3) driver identification to prevent unauthorized use, (4) capability of gradually decelerating the vehicle to a stop and disabling the engine (remote deceleration and shutdown), and (5) trailer door security. The installed sensors include GPS, speedometer, and odometer. This system includes a small display and voice activation.

### *2.3.4. Accident Prevention Plus*

The main goals of APP system are to provide security for unauthorized use of vehicle and monitor vehicle operational data for accident prevention. Other goals include use for driver training, driver evaluation, and maintenance purposes. More specifically, their system can: (1) prevent unauthorized use of a vehicle, (2) monitor operational data (speed, engine speed, fuel consumption, acceleration/deceleration, gear position, brake on/off, lights on/off), (3) record 50 sec. before and 10 sec. after an accident. The operational data that is collected includes driving chronologies, idling chronologies, 20 most recent speed violations, maximum speed, maximum acceleration/deceleration, speed histograms, engine speed histograms, brake intensity histograms, brake occurrence, speed ranges, and gear position histograms. The system also records distance driven, maximum speed, and the number of driving periods above a selected duration. The employed sensors include speedometer, accelerometer, tachometer, fuel rate sensor, gear position sensor, braking (on/off), lights (on/off). This system does not include any interface to interact with the driver as it functions mostly as a "black box" recording data for off-line analysis.

### *2.3.5. Cadec*

The purpose of the Cadec's Mobius TTS system is to provide a paperless tracking and delivery system; however, it has additional features concerning safety, security, and government logging compliance. Audible and visual warnings from the onboard computer help keep the drivers informed and alert so they can maintain safe vehicle handling practices. This system includes the following features: (1) wireless communication, (2) trailer temperature tracking, (3) trailer door tracking (open or closed for security), (4) route tracking, (5) coaching driver to adhere to company standards via display and audio, and (6) border crossing notification (US only). The installed sensors consist of speedometer, odometer, GPS, and tachometer. A touch screen display is used to communicate with the driver. The onboard computer can give audible and visual warnings to alert the driver.

### *2.3.6. QualCOMM*

The purpose of QualCOMM's SensorTRACS is to send on-board sensor information to dispatch over the air to improve driver performance and safety and to analyze the fleet productivity and operation. The system proclaims that the advantage of the wireless communication is that data can be collected without driver intervention and that the fleet management team can feedback on driver performance near real-time. This system can:

(1) increase fuel savings by reducing over-idle, over-revving, and excessive speed and (2) reduce engine wear and hard braking. The employed sensors include speedometer, odometer, throttle position sensor, and tachometer. This system uses text messages on a display to alert the driver.

#### *2.3.7. DriveCam*

The main purpose of the DriveCam's system is safety and driver training. The system integrates video technology and management software to identify high-risk driving habits, particularly, it records large g-force events such as collisions. Their system can record 10 seconds of audio and video both before and after a large g-force event or accident. The g-force threshold is adjustable and can be adapted to different vehicles. The employed sensors include accelerometers and camcorders, which are used to record events and accidents. The DriveCam system focuses entirely on recording video of what's going on inside and outside the vehicle, as opposed to recording any engine-based performance measures. The only feedback provided by the system is real-time feedback in the form of a light which lets the driver know that an incident has occurred and triggered the cameras to save their recorded data.

#### *2.3.8. AllTrackUSA*

AllTrackUSA (.com) makes several products for real-time fleet asset tracking through the use of GPS; however, the only driver monitoring system currently being advertised by the company is targeted towards teen drivers. The black box device monitors aggressive driving using an accelerometer and a connection to the vehicle's CAN bus to read parameters such as engine speed and accelerator position. Driver feedback is provided in real-time in the form of a loud beep whenever aggressive driving (high-g maneuvers) are made. Off-line, driver reports can be downloaded.

#### *2.3.9. DriveDiagnostics*

DriveDiagnostics, Ltd., is an Israeli start-up that intends to make products for monitoring both teen drivers and fleet vehicles. Very little information is freely available on any of their upcoming products. Based on the web descriptions of their future products, they will likely contain, at minimum, GPS and accelerometers. Feedback will likely be given in the form of reports generated off-line after downloading the data.

#### *2.3.10. COTS Summary and Conclusions*

The COTS systems built specifically for the trucking industry generally focus on fleet maintenance, asset tracking, and on saving operations costs, but many have features related to driver monitoring and safety. Generally, as a result, these systems monitor driver behaviors from the perspective of the vehicle's mechanical conditions and motions.

The systems specifically focused on safety rely almost entirely on high-g incidents as the primary measure of driver safety. While high-g incidents might be one measure of "unsafe" driving, they most certainly aren't the only measure. It is clear that none of these individual products are comprehensive from the standpoint of monitoring safety related driver behavior.

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# 3. DELINEATING CAUSAL FACTORS IN CRASHES

## 3.1. Introduction

Three methods have commonly been employed to approach the problem of heavy vehicle crash causation. First, panels of drivers or experts have been consulted come up with lists of safety issues in the trucking industry and "unsafe" driving behaviors. While these methods are completely subjective, they are based on drivers' experiences and often provide a useful perspective.

Second, many studies have mined the crash statistics associated with large trucks with some success. Unfortunately, crash reports, as currently recorded in the United States, are often vague and lacking in important details, and thus, do not necessarily reflect or contain the true causes of a crash. Additionally, many of past studies which are reviewed in this section have tried to categorize or examine crashes in terms of "fault", which is a fairly subjective designation and should be read as such.

In response to these sorts of issues, a third approach, the Large Truck Crash Causation Study (LTCCS), addresses the problem with a more robust perspective and method. Instead of trying to determine "cause" or "fault" directly, the LTCCS addresses "cause" in terms of critical events, critical errors that lead to those events, and contributing factors. Unfortunately, this study is still in-progress, so all of the data that has been presented to date and reviewed in this report is preliminary at best.

## 3.2. Safety Issues from the Trucking Industry

### *3.2.1. <u>Studies in the U.S.</u>*

In 2003, the first in a series of TRB reports on Commercial Truck and Bus Safety was published. In this report (Knipling, Hickman, and Bergoffen, 2003) surveyed commercial motor vehicle (CMV) fleet managers and experts in motor vehicle safety on importance of 20 perceived safety problem areas in the trucking industry. The top 9 issues that were found are listed below:

1. At-risk driving behaviors (e.g., speeding, tailgating)
2. Individual high-risk drivers (all causes combined)
3. Lifestyle or general health issues (e.g., poor diet, smoking)
4. Lack of defensive driving skills (poor space management)
5. Delays associated with loading and unloading cargo
6. Driver fatigue/drowsiness
7. Aggressive driving
8. Heart Disease
9. Poor attitude, morale, emotional state

Of these nine issues, at risk driving behaviors, defensive driving skills, fatigue, and aggressive driving are all potential candidates for an onboard monitoring system. Although aggressive driving could not be specifically defined, the report went on to define the following as at-risk driving behaviors (many based upon prior studies and crash data):

- Speeding
- Excessive speed on curves or in relation to weather conditions
- Improper following distance
- Lateral encroachment (e.g., during lane changes, due to improper mirror adjustment)
- Failure to yield at intersection
- General disobedience of the rules-of-the-road

The specifics of space management and defensive driving skills were left somewhat undefined. The general concept of space management refers to the fact that large trucks have large blind spots and limited maneuverability when reacting to actions taken by automobile drivers. In effect, space management refers to the need for truck drivers to preventively compensate for any poor decisions being made in their presence because many crashes between trucks and automobiles tend to be primarily attributed to the actions of the automobile driver.

Finally, the Knipling, Hickman, and Bergoffen (2003) reported provided a good discussion on the issue of fatigue. While it had been widely reported that fatigue was a large problem and a factor in 31 percent of single-vehicle ran-off-the-road crashes where the truck driver was killed, this particular crash type only accounts for 1 in 7 fatal truck crashes and 1 in 700 overall truck crashes. Thus, when considering truck crashes overall, the issue of fatigue is ranked as a somewhat lower priority and possibly one that is limited mostly to specific segments of the trucking industry.

While the study described above interviewed fleet managers and safety experts, two recent studies surveyed truck drivers about their safety concerns. Hanowski, et. al. (1998) conducted 11 focus groups across 5 states with a total of 82 local and short haul (L/SH) truck drivers. Across all sessions, the top five critical issues or crash causal factors as seen by drivers were as follows (ranked in order of importance to the drivers):

1. Problems caused by drivers of light vehicles
2. Stress due to time pressure
3. Inattention
4. Problems caused by roadway or dock design
5. Fatigue

The problems caused by the drivers of light vehicles, although ranked as the most important safety issue, was generally described in vague terms, such as light vehicle drivers don't show trucks enough respect. Specifically, cut-ins and backing were listed as problems with light vehicles. Interestingly, inattention was listed as one of the top 5 safety issues by drivers in this study, but there was no mention of it by management in the previous study. However, inattention, in the context of L/SH drivers, seemed to refer to the issues of multitasking while driving, such as planning your next stop or delivery or having to navigate with ineffective road signage. Similarly, fatigue, in the eyes of L/SH drivers, was used more in the context of mental fatigue as opposed to actually falling asleep at the wheel. Since L/SH drivers tend to work during daylight hours and have frequent breaks (deliveries) to interrupt their driving, fatigue is simply the result of a normal day's work, which can be exacerbated by excessive heat (a lack of A/C in their vehicles) or irregular meal times.

Finally, Roetting, Huang, and McDevitt (2005) surveyed 239 long and short haul drivers specifically asking them to rank the importance of several critical safety behaviors. The drivers were presented with 10 behaviors and asked to select their top 3. The results are shown below in Table 4.

Table 4. Critical Safety Behaviors or Issues.

| Rank | Critical Safety Behaviors or Issues | % of Drivers Ranking in their "Top 3" |
|---|---|---|
| 1 | Looking far enough ahead and anticipating changes | 74.4 |
| 2 | Being ready to avoid the mistakes of other drivers | 55.4 |
| 3 | Turn signal use in advance of lane changes | 48.7 |
| 4 | Properly adjusting mirrors to prevent blind spots | 29.2 |
| 5 | Drowsy driving | 28.2 |
| 6 | Speeding | 17.4 |
| 7 | Seatbelt usage | 16.4 |
| 8 | Following too close | 13.3 |
| 9 | Distracting driving | 8.7 |
| 10 | Being courteous to other drivers | 8.7 |

### *3.2.2. <u>International Studies</u>*

In New Zealand, Sullman, Meadows, and Pajo (2002) surveyed 382 truck drivers on the topic of aberrant driving behaviors falling into 3 categories:

1. Errors
2. Lapses
3. Violations

Errors included such things as failures of observation and misjudgments, e.g., braking too hard on a slippery road. Lapses were considered as failures of attention, and violations were deliberate actions such as speeding or tailgating. The questionnaire asked drivers to self-report on a scale of 0 (never) to 5 (all the time) how often they engaged in or experienced a particular behavior. Of the 3 categories, only responses to the questions on violations were predictive of increased crash risk. The most commonly reported behaviors in each category (those with a mean score above 0.5) are listed below in Table 5.

Table 5. Most common self-reported aberrant driving behaviors in New Zealand.

| Errors | Lapses | Violations | Aggressive Driving |
|---|---|---|---|
| Underestimating the speed on an oncoming vehicle while overtaking | Getting into the wrong lane at a junction | Speeding | Honking at others |
| | Having no recollection of the road you just traveled | Tailgating | Showing hostility |
| | Hitting the wrong control in the vehicle | Running a red light | Racing away from a traffic light |
| | Starting in the wrong gear | | |
| | Backing into an object | | |

In Finland, Häkkänen and Summala (2001) surveyed 251 long-haul drivers, asking them to rank 8 safety issues from the most common to the least common cause of crashes. The results are listed below in rank order from most to least common:

1. Other road users
2. Errors in truck driver perception or judgment
3. Speeding
4. Weather
5. Fatigue
6. Errors in operating the vehicle
7. Traffic environment
8. Technology faults

Unfortunately, greater detail on what was meant specifically by errors in perception or judgment or errors in operating the vehicle was not available. However, the country of Finland is somewhat unique in that every fatal crash involving large trucks has been investigated by a panel of experts to determine what factors were relevant in the cause of the crash. From 1991 to 1997, it was found that in 83 percent of the crashes involving large trucks, the truck driver was not primarily at fault. Similar to the U.S. conclusions, this evidence supports the truck drivers' view that other road users are the most common cause of crashes. In the 17 percent of crashes where the truck driver was primarily at fault, the breakdown by crash type is listed below in Table 6.

Table 6. Fatal crash type distribution when the truck driver was primarily responsible.

| Rank | Crash Type | % |
|---|---|---|
| 1 | Opposite direction or head-on collision | 50.9 |
| 2 | Same direction (overtaking, change of lane or rear-end collision) | 17.5 |
| 3 | Same direction with one vehicle turning | 10.5 |
| 4 | Intersection straight crossing path | 8.8 |
| 5 | Intersection with one vehicle turning into or across path | 5.3 |
| - | Opposite direction with one vehicle turning | 0.0 |
| - | Other | 7.0 |
| Total | | 100.0 |

The high prevalence of opposite direction head-on collisions is probably due to the fact that most of the roads traversed by trucks in Finland are two-lane highways. A different crash type distribution would probably be expected in the U.S. where multi-lane freeways are more common. In addition to determining which driver was primarily at fault, the panel of experts also made determinations about casual factors. Table 7 shows the percentage of crashes attributed to each causal factor. Over 50 percent of the fatal truck crashes where the truck driver was primarily at fault were attributed to errors in attention, anticipation, or estimation, and 26 percent were attributed to errors in operating the vehicle. Unfortunately, specific details were not given on these two classifications.

Table 7. Fatal crash casual factors when the truck driver was primarily responsible.

| Rank | Causal Factor | % |
|---|---|---|
| 1 | Error in attention, anticipation or estimation | 50.8 |
| 2 | Error in operating the vehicle | 26.3 |
| 3 | Technological faults | 7.0 |
| 4 | Driver having fallen asleep while driving | 5.3 |
| 5 | Attack of illness | 1.8 |
| 6 | Traffic environment | 1.8 |
| - | Other reasons | 7.0 |
| Total | | 100.0 |

### 3.3. U.S. Crash Statistics

There have been numerous studies employing various methods to analyze the crash statistics when large trucks are involved. In the United States, the Center for National Truck and Bus Statistics at the University of Michigan Transportation Research Institute (UMTRI) publishes a yearly Trucks Involved in Fatal Accidents Factbook, which combines data from the Fatality Analysis Reporting System (FARS) with follow-up surveys. From the latest factbook (Matteson, Blower, and Woodruffe, 2004), Table 8 summarizes the types of fatal crashes in which trucks are typically involved. It is interesting to note that when it comes to fatal crashes, the percentage of crashes is fairly evenly distributed among crash types. The largest single category of crash type involvement is single vehicle, either ran-off-the-road or hit an object in the road. The second largest category was rear end collisions, with the truck being the striking vehicle 38 percent of the time. Interestingly, for sideswipe and head-on collisions, the crashes typically occurred with the other vehicle striking the truck or in the truck's lane. However, for straight crossing path collisions (at intersections), the truck typically did the striking, which is probably a reflection of the well known rural crash paradigm where light vehicle drivers pull out in front of an oncoming truck having misjudged the truck's distance and speed.

Table 8. Trucks Involved in Fatal Crashes by Crash Type.

| Crash Type | Truck Striking (In Other Vehicle's Lane) | Other Vehicle Striking (In Truck's Lane) | Total (%) |
|---|---|---|---|
| Single Vehicle | - | - | 14.4 |
| Rear End | 5.1 | 8.2 | 13.3 |
| Sideswipe | 2.2 | 10.2 | 12.4 |
| Intersection (Straight Crossing) | 8.0 | 3.2 | 11.2 |
| Head-on | 1.1 | 9.2 | 10.3 |
| Intersection (Across Path Turn) | - | - | 9.2 |
| Backing | 0.5 | 0.1 | 0.6 |
| *Other* | | | *15.5* |
| *Unknown* | | | *13.2* |
| Total | | | 100 |

Another important study, Council, Harkey, Nabors, Khattak, and Mohamedshah (2003), examined the North Caroliana crash database from 1994 to 1997 which included 16,264 car-truck crashes. Although this database is not national, it includes all crashes, not just fatal crashes. What is most interesting to note is that while national studies of fatal truck crashes have shown that car drivers were considered "at fault" for the crash almost 70 percent of the time, truck drivers may share more of the blame when it comes to overall or non-fatal crashes. As shown in Table 9, Council et al. (2003) found that overall, "fault" was more evenly split with 48 percent of crashes being attributed to the truck driver and 40.2 percent being attributed to the car driver (with the remaining being attributed to both or neither).

Table 9. Fault distribution of accident types.

| Crash Type | % Truck "at Fault" | % Car "at Fault" | Total % |
|---|---|---|---|
| Rear-end (slow) | 50.7 | 41.0 | 25.8 |
| Rear-end (turning) | 51.5 | 36.0 | 2.4 |
| Left turn (same roadway) | 45.4 | 38.6 | 8.7 |
| Left turn (crossing traffic) | 42.9 | 48.4 | 5.9 |
| Right turn (same roadway) | 43.1 | 35.5 | 4.7 |
| Right turn (crossing traffic) | 36.2 | 54.4 | 2.3 |
| Head-on | 22.5 | 71.2 | 1.4 |
| Sideswipe | 51.1 | 35.1 | 21.8 |
| Angle | 39.3 | 48.5 | 21.4 |
| Backing | 81.5 | 9.7 | 5.5 |
| Total | 48.0 | 40.2 | 100.0 |

Interestingly, most of the crash types show a fairly even split between car and truck drivers, however, there were several crash types with large disparities. Crashes that involved backing or rear-end crashes while turning were much more often the fault of the truck driver, although these two categories accounted for only 7.9 percent of the overall crashes. The largest overall category where truck drivers were most at fault was in sideswipe crashes which account for 21.8 percent. Although a detailed description was not given for this crash type, process of elimination would suggest that the authors are referring to intersection straight crossing path collisions.

### 3.4. The Large Truck Crash Causation Study

Recognizing that surveys of truck drivers and industry experts and crash statistics as currently gathered have flaws, perhaps the most definitive work which will come on the topic of truck crashes is the Large Truck Crash Causation Study (LTCCS). This joint study between FMCSA and NHTSA was currently still in progress at the time of this report. An interim report on the project status (Blower and Campbell, 2002) laid out the methodology for the study. The study was seeking to build a national sample of over 1000 fatal and serious injury crashes with supplemental information gathered to allow the coding of a critical event, a critical reason for the critical event, and other crash related factors. The critical event is defined as the action or event that put the vehicles on a collision course. The critical reason is defined as the immediate reason for the critical event.

The distribution of critical events for two-vehicle crashes is detailed in Table 10 based on presentation of the LTCCS interim results (Craft and Blower, 2004). At the time of this report, the LTCCS had only examined 589 raw crash samples and only 287 of those crashes were two-vehicle crashes between a car and a truck. The largest 3 categories of critical events (almost 80 percent of the crashes) included driving out of the lane, turning at or crossing intersections, and rear-end crashes.

Table 10. LTCCS critical events broken by vehicle exhibiting the critical event.

| Critical Event (for two-vehicle crashes) | Truck (%) | Other Vehicle (%) | Total Crashes (%) |
|---|---|---|---|
| Vehicle | 1 | 1 | 1 |
| Roadway or environment | 0 | 3 | 2 |
| Loss of control (driving too fast) | 3 | 10 | 8 |
| Driving over the lane or off the road (including head-on and lane change) | 35 | 29 | 30 |
| Turning at or crossing an intersection | 27 | 28 | 28 |
| Same lane (rear-end) | 28 | 27 | 26 |
| Other | 8 | 3 | 5 |
| Total | 100 | 100 | 100 |

Although the results in Table 10 somewhat resemble past studies detailing crash type by fault, the power of the LTCCS is in the fact that it goes beyond just crash type. As shown in Table 11, the critical reasons for the critical events are shown for the same two-vehicle crashes described in Table 10. The largest critical reason found for two-vehicle crashes was inattention, followed closely by poor decisions or misjudgment. These two factors alone account for over 80 percent of two-vehicle crashes attributed to truck drivers.

Table 11. The critical reason for two-vehicle crashes with trucks.

| Critical Reason | Truck (%) | Other Vehicle (%) | Total (%) |
|---|---|---|---|
| Vehicle (typically brake failure) | 6 | 4 | 5 |
| Environment | 0 | 6 | 4 |
| Driver nonperformance (sleep or sickness) | 3 | 11 | 9 |
| Driver recognition (inattention or external distractions) | 46 | 34 | 38 |
| Driver decisions (misjudgments) | 36 | 20 | 25 |
| Driver performance (poor control) | 5 | 9 | 8 |
| Driver unknown errors | 3 | 13 | 10 |
| Other/unknown | 1 | 3 | 2 |
| Total | 100 | 100 | 100 |

Inattention or distraction was also found frequently as a related factor in the crash. Internal distractions were found to be related to almost 17 percent of the two-vehicle crashes, and external distractions were found to be related to almost 8 percent of the two-vehicle crashes. Poor surveillance, driving too fast, and making false assumptions were each found to be related to about 10 percent of the crashes, but following too close was only a factor in 4 percent of the crashes. By far, the largest related factor was prescription or over-the-counter medications which were a factor in almost 34 percent of the two-vehicle crashes.

The results described in the tables above for the critical reasons of two-vehicle truck crashes hold fairly true when looking at all truck crashes. For all truck crashes, 53 percent of the time the critical reason was not associated with the truck or truck driver. Nearly 31 percent of the crashes could be attributed to driver inattention, distraction, misjudgments, or poor decisions. Only 4 percent of crashes could be attributed to sleep or sickness, and only 4 percent of crashes could be attributed to poor vehicle control. Finally, a full 5 percent of crashes could be attributed to vehicle failures (typically brakes), meaning that the top 5 critical reasons accounted for almost 97 percent of crashes.

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# 4. SUMMARY AND CONCLUSIONS

This report covered two topics. First, it provided background on the topic of onboard driver monitoring systems, and second, it reviewed the recent literature on the topic of delineating causal factors for large truck crashes. The concept of an onboard driver monitoring system has been born from the behavior-based safety approach which aims to identify “unsafe” behaviors, monitor those behaviors, and feedback to encourage good behavior and discourage the “unsafe” behavior.

Four studies were reviewed on the general topic of driver monitoring systems in the trucking industry. Each of the studies surveyed drivers, managers, or industry experts to gather their input on the concept of driver monitoring, all of the studies came to the same conclusions. Although privacy and misuse of the data were of primary concern, there was general acceptance within the industry for the concept of driver monitoring. Unsurprisingly, acceptance was also a function of perceived benefit. The more benefit the drivers saw in the individual system, the more positive they were towards accepting the overall concept of onboard monitoring.

In regard to the delineation of causal factors in large truck crashes, three types of studies were presented, those that interviewed industry experts, those reviewed crash statistics, and the currently in progress Large Truck Crash Causation Study (LTCCS). Although, all of these sources had both advantages and disadvantages, the results of the LTCCS, even though preliminary, can probably be thought of as carrying the most weight, while the other studies can be thought of as providing confirming evidence.

Based on the findings of the LTCCS, three general categories of critical events leading to crashes could be considered high priority: (1) driving over the lane or off the road, (2) turning at or crossing an intersection, and (3) rear-end collisions. The most common reasons for the critical event were driver errors in recognitions (due to inattention or distraction) and errors in decisions (misjudgments). In support of this assertion, the industry experts, truck drivers, fleet managers, and safety experts, all agreed that inattention and distraction are major problems which need to be addressed.

Industry experts, truck drivers, fleet managers, and safety experts, also all agreed that aggressive or risky truck driver behaviors, such as speeding or tailgating, were of great concern. However, contrary to popular belief, most studies agree that fatigue, in the sense of falling asleep at the wheel, is a much lower priority and only a primary factor in maybe 3 percent of truck caused crashes. Vehicle failures, typically brakes, were only responsible for 5 to 6 percent of crashes according to the LTCCS.

These results provide a sound basis and background for the first step of the behavior-based safety approach, identifying the “unsafe” behaviors. The focus of the next phase of this project should revolve around translating the critical events and critical reasons into “unsafe” driving behaviors that can be monitored with in-vehicle technologies.