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THE EFFECTS OF TECHNOLOGIES ON COMMERCIAL VEHICLE COMPANY SAFETY AND SERVICE: A SUPPLY CHAIN PERSPECTIVE

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Brenda M. Lantz

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The thesis of Brenda M. Lantz was reviewed and approved* by the following:

Peter F. Swan
Assistant Professor of Logistics and Operations Management
Thesis Adviser
Co-Chair of Committee

Alan J. Stenger
Professor of Supply Chain Management
Co-Chair of Committee

John C. Spychalski
Professor of Supply Chain Management

Paul P. Jovanis
Professor of Civil and Environmental Engineering

John E. Tyworth
Professor of Supply Chain Management
Chair of the Department of Supply Chain and Information Systems

*Signatures are on file in the Graduate School.

ABSTRACT

Because of the importance of safety, and the potential benefits for both the general public and the commercial vehicle industry of improving safety, the main goal of this project was to identify those commercial vehicle-related technologies that, through successful adoption, have had a positive impact on the safety of motor carrier companies. This was examined through two perspectives — one simply examining the effect of a technology implementation on safety, and the second identifying the effect of a successful adoption of a technology on safety. It was hypothesized that technologies with factors that lead to successful adoption will have a greater safety impact.

Negative binomial regression models with the dependent variables of three separate measures of safety were utilized to test each technology, and the overall results were mixed. The models for on-board safety monitoring technologies (that did not rate high on average for any adoption factor) illustrated no significant effect on safety; however, the models for technologies in both the freight mobility area and the electronic clearance area illustrated a negative effect on safety. In addition, the results for two specific technologies revealed that the companies who have implemented these technologies and rated the adoption factors higher (e.g., successfully adopted the technology) are likely to have fewer accidents than companies who implemented these technologies and rated the adoption factors lower.

The main implication of this study for both commercial vehicle companies and government agencies is that simply implementing a technology, or advocating implementing a technology, may not give a desired result, and in some cases may even result in a negative impact on safety. The company needs to take the time to learn the technology and integrate it fully into the company in the right way in order for it to have a positive impact. Similarly, government agencies should examine companies that have successfully implemented certain technologies and that have a good safety record to determine the steps they took during the implementation. Providing this information to other companies examining implementing a technology could prove very useful and assist them toward a positive safety impact from the technology.

TABLE OF CONTENTS

LIST OF TABLES

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CHAPTER 1. INTRODUCTION

> *"A diverse set of alliances that includes the Federal Highway Administration, state departments of transportation, manufacturers, business and academia is transforming the technology ideas of tomorrow into the transportation realities of today"* (Reed, Goehring, and Pattarozzi 1996).

Anyone who has traveled our nation's highways realizes that the amount of traffic and congestion continues to increase. One may also notice that the number of commercial vehicles traveling on our highways has increased as well. In fact, since 1980, there has been over a 75 percent increase in truck vehicle miles traveled (Eno Transportation Foundation 2000). With this increase, there is a logical increase in the vehicles involved in crashes as well, and crashes that involve a heavy commercial vehicle are likely to be much more serious. Many different groups, including government, private industry, and the public, have an interest in continually trying to find ways to lower the number of crashes that occur. One avenue to explore to help accomplish this is the use of technology.

Because of the importance of safety, and the potential benefits for both the general public and the commercial vehicle industry of improving safety, the main goal of this study is to identify those commercial vehicle-related technologies that, through successful adoption, have had a positive impact on the safety of motor carrier companies. This will be examined through two perspectives, one simply examining the effect of a technology implementation on safety, and the second identifying the effect of a successful adoption of a technology (as compared to a less successful adoption of a technology) on safety. It is anticipated that the information discovered in this project could be used by commercial vehicle companies to aid them in implementing technologies that will be of the greatest benefit to both them and their customers. In addition, the information could be used by government agencies to help them to target their efforts towards advocating the implementation of technologies that have the greatest potential safety impact.

1.1 Description of the Commercial Vehicle Industry

The commercial vehicle industry is vital to the U.S. economy. In 2004, commercial vehicles transported 9.8 billion tons of freight, which represented 68 percent of the total domestic tonnage of freight shipped. The commercial vehicle industry earned $610 billion in gross freight revenues in 2003, which equates to 87 percent of the U.S. freight bill (American Trucking Associations 2004). However, since 1980, while there has been over a 75 percent increase in truck traffic, truckload carriers have experienced over a 7 percent decrease in their average real freight rates (Eno Transportation Foundation 2000).

The trucking industry is extremely competitive. With the enactment of the Motor Carrier Act of 1980, and the associated alleviation of regulatory entry and rate controls, substantial numbers of carriers have entered the industry contributing to the decline in freight rates. Specifically, the MCA of 1980 ended the requirement for a potential new trucking company to prove there was a need for their service to fulfill "public convenience and necessity." Without this requirement, it became relatively simple to start up a trucking company.

Prior to deregulation, there were fewer than 20,000 interstate motor carriers in the U.S. By July 2004, there were more than 524,000 carriers registered with the U.S. Department of Transportation. These include for-hire companies, private companies, and owner-operators. The majority of these companies, approximately 93 percent, operate 20 or fewer trucks. As a result, the commercial vehicle industry is very fragmented with intense competition (American Trucking Associations 2004). Companies must vie for business through both lower rates and superior service.

An important strategic option in this competitive environment is to leverage new technologies. However, without actual implementation of the technology, it is difficult if not impossible to determine the effect it will have on service and safety. Thus, the main objective of the present study is to evaluate the effects of various technologies on safety and service. In addition, methods to quantify the benefits of those effects from a supply chain perspective are discussed. The results of this research are important to the commercial vehicle industry, supply chain managers, policy makers, and the general public.

One potential strategy for a motor carrier company to better its service offering is through investment in technology. However, as indicated in one *Transport Topics* article, "Trucking companies risk being drowned by the flood of technologies and logistics services coming onto the market . . .a quandary for trucking's IT professionals: how to know which technologies will improve the way they do business and which may saddle them with extraneous information . . . to compete, trucking companies will have to provide better, faster service and at less cost" (Whitten 1999). As this quote illustrates, commercial trucking companies are in a precarious position; they may realize that they need to invest in technology to remain competitive, but many appear to be unsure about which innovations will give them the desired results.

The right technology can conceivably help a carrier in a variety of ways. For example, computer technology has enabled commercial vehicle routing and scheduling to become routine. Entire supply chains can now be simulated to determine the best approach to meet a company's objectives. The advent of Electronic Data Interchange, the Internet, bar coding, and satellite transmission have all helped to integrate the supply chain and increase its efficiency as well as effectiveness (Coyle, Bardi, and Langley 1996).

A company's "bottom line" is impacted not only by reductions in costs, but by increases in revenues, through improved customer service for example. The right technology, implemented correctly, can affect both of these areas. Examples of possible effects include improved on-time performance, and improved equipment and driver utilization, as well as reduced en-route delays, accidents, empty miles, and administrative costs.

The ability to leverage new technologies is an important competitive weapon in the commercial vehicle industry. Because of the large number of commercial vehicle companies available, a shipper is able to shop around for the lowest price carrier. Therefore, in order to obtain and retain business, companies must compete on service and safety record, as well as price. Investment in new technologies offers important ways to improve safety and service. The challenge, however, is to determine which technologies offer the best payoff in terms of safety and service.

Helping to answer this question is the main goal of this project. Although several studies have explored some of the benefits of certain technologies to motor carriers, thus far, not one has explored the very important link between implementing technology and improving safety.

1.2 Service and Safety Record

The service and safety record of a company are intertwined. It is expected that if a company improves its safety record, its service will improve as well. In addition, safety is a critical element of both carrier strategy and public policy, and technology is seen by both parties as a potential way to improve safety.

The key elements of carrier service are transit time, reliability, capability, accessibility, and security. Safety plays a role with regards to three of these elements — transit time, reliability, and security. The fewer accidents and safety violations a carrier has, the shorter their transit time, the more reliable they are, and the more secure transports of cargo they will have.

Highway accidents are a continual reality for the commercial vehicle industry. With the continuous increase in truck traffic and associated vehicle miles traveled, there are currently more than 450,000 traffic crashes involving large commercial vehicles per year. Besides the societal costs of accidents that impact the company, such as personal injury, property damage, and traffic congestion, there are commercial costs, such as damage to vehicles and cargo, increased insurance premiums, and degraded delivery performance.

The area of safety, although always a priority, is particularly applicable at the present time. In January 2000, a new agency, the Federal Motor Carrier Safety Administration (FMCSA), was created within the U.S. Department of Transportation (DOT). This is the only modal administration under the DOT (i.e., among the Federal Aviation Administration, the Federal Highway Administration, the Federal Railroad Administration, the Federal Transit Administration, and the Maritime Administration) that has the word “safety” in its name, and it is to stress its main strategic goal. In fact, FMCSA has set a very ambitious goal to reduce the large truck fatality rate by 41 percent from 1996 to 2008. This reduction translates into a rate of 1.65 fatalities in truck crashes per 100 million miles of truck travel. It is anticipated that the information discovered in the present project will help the FMCSA to target its efforts towards advocating the technologies that will have the greatest impact on safety.

From the motor carrier company perspective, safety is also a very important issue. This concern will continue to be the case as the ever-increasing traffic (commercial vehicles and passenger cars) increases the likelihood of accidents. Besides the obvious societal costs of accidents that will impact the company, such as pain and suffering, loss of productivity of anyone injured or killed, police and medical personnel expenses, property damage, traffic delays, etc., there are other important costs to the motor carrier. These costs include the damage to the commercial vehicle and cargo, and the necessity to provide another vehicle and/or cargo to complete the delivery. Other consequences may include negative publicity, higher insurance rates, and the loss of future business. For all these reasons, companies are searching for ways in which they can utilize technology not only to provide increased efficiency in their supply chain in today's just-in-time environment, but to help them improve safety.

Given the importance of safety and controlling for other factors as much as possible, this study will identify which technologies motor carriers have implemented that have had an impact on safety. Technology adoption theory is used to explore specific aspects of the technologies that led to their successful adoption. It is hypothesized that technologies with factors that lead to successful adoption will have a greater safety impact. In addition, use of an inventory-theoretic model is presented as an example of one way to measure the full range of benefits to the company from successful technology implementation.

There already exists a nationwide database of interstate motor carriers maintained by the U.S. Department of Transportation which contains safety-related information. Therefore, the only additional information needed to conduct the analysis is which technologies motor carriers have in place and the innovation adoption factors associated with the technology. Unfortunately, no database currently exists that has this information. Thus, a survey of a stratified random sample or carriers is used to obtain the necessary data.

The remainder of this paper includes a literature review in Chapter 2 detailing the theoretical background of user acceptance and technology adoption, research completed to date regarding benefits of certain technologies for motor carriers, a brief description of inventory-theoretic models as one way to illustrate benefits, and a description of known factors related to commercial vehicle safety. Chapter 3 details the specific hypotheses proposed and tested for the present study, as well as a description of the various technologies available for commercial vehicle operations. Chapter 4 describes the research objectives and methodology used for this study and Chapter 5 details the analysis and results. Finally, Chapter 6 presents a summary and conclusions. There is also an appendix — Appendix A — that contains a replica of the technology survey that was distributed to the companies.

CHAPTER 2. LITERATURE REVIEW

From an extensive literature review and the author's personal conversations and experience in this area, one point is readily apparent. Although there appears to be little disagreement about the *potential* benefits of technology, the literature regarding direct measured benefits is lacking, particularly in the area of safety benefits. In this chapter, a theoretical background regarding technology adoption theory is presented along with information regarding research specifically related to commercial vehicle technology benefits. In addition, a brief review of the current literature regarding use of transportation-inventory models as a possible way to measure benefits is presented. The chapter concludes with a discussion regarding known factors related to commercial vehicle safety from prior research.

2.1 Theoretical Background

Within the field of user acceptance and technology / innovation adoption, there are two main well-established theories – the technology acceptance model (TAM) and innovation diffusion theory (IDT).

First introduced by Davis (1989), the technology acceptance model focuses on the two main constructs of perceived usefulness and perceived ease of use of a system. A literature scan produces almost 500 articles related to the use of this model (see, for example, Chen, Gillenson, and Sherrell, 2002; and Ma and Liu, 2004). Perceived usefulness is defined by Davis (1989) as "the degree to which a person believes that using a particular system would enhance his or her job performance," and perceived ease of use is defined as "the degree to which a person believes that using a particular system would be free of effort." Davis and other researchers have operationalized these constructs in their research and find both are significantly correlated with system use.

Similar to TAM, innovation diffusion theory defines a set of attributes to help explain the adoption rate of users. These attributes are relative advantage, compatibility, complexity, trialability, visibility, and observability (Rogers 1995). These are defined by Rogers as follows:

- Relative Advantage: The degree to which an innovation is perceived as being better than the idea it supersedes. The degree of relative advantage is often expressed as economic profitability, social prestige, or other benefits.
- Compatibility: The degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters.
- Complexity: The degree to which an innovation is perceived as relatively difficult to understand and use.
- Trialability: The degree to which an innovation may be experimented with on a limited basis.
- Observability: The degree to which the results of an innovation are visible to others.

Rogers consolidated more than 1,500 studies into this theory, and as with TAM, innovation diffusion theory is widely accepted with more than 250 articles related to its use (see, for example, Jurison 2000, and Redmond 2003).

Examining the definitions of the constructs for each theory, it is noticeable that the “perceived usefulness” construct of TAM is very similar to the “relative advantage” construct of IDT. In addition, the “perceived ease of use” construct is similar to the “complexity” construct. This lends credence to both theories that the findings of each confirm the other.

In fact, Rogers (1995) concludes that relative advantage is one of the best predictors of the rate of adoption of an innovation. This is confirmed by Jurison (2000) who performed a three-year study in an engineering company of an information system implementation. The applications of the system that were perceived to offer high relative advantage were adopted more rapidly. Parthasarathy and Bhattacherjee (1998) found that both relative advantage and compatibility were significant predictors of adoptive behavior in their research of online services. And, Premkumar et al (1997) also found relative advantage to be the best innovation attribute to predict electronic data interchange adoption in the transportation industry. A literature search through ProQuest identified 469 scholarly journal articles that have utilized either TAM or IDT; however, to date there has been only one, Premkumar et al (1997), that has attempted to apply either of these theories to the service industry of transportation. This study was specifically related to electronic data interchange and did not explore any other technologies.

Many of the authors operationalized the five attributes in a form of a survey to conduct their research. These will be synthesized for use in the present study as illustrated in Chapter 4.

2.2 Benefits of Technologies for Motor Carriers

A thorough compilation of all studies that document the experience with, and the prediction of, benefits in every area of Intelligent Transportation Systems (ITS) technologies was first prepared in 1997 (Proper and Cheslow 1997). There was an update to this compilation published in 1999, 2001, and 2003, with an associated Internet web site created for continual updates (Mitretek Systems 2003). The authors use measures created by the Federal Highway Administration to analyze the effects of ITS. These measures are crashes, fatalities, travel time, throughput, user satisfaction or user acceptance, and cost. They examine if each of the studies provides measured, anecdotal, and/or predicted benefits in each area. Under commercial vehicle operations (CVO), there have been studies related to the benefits of ITS/CVO which have provided anecdotal evidence regarding crashes; predicted evidence regarding fatalities; measured and predicted documentation regarding time; measured, anecdotal, and predicted documentation regarding cost; and measured and predicted documentation of customer satisfaction. There has been nothing noted in the area of throughput, and no measured evidence regarding crashes or fatalities (Proper and Cheslow 1997).

Table 1 displays a summary of the ITS/CVO benefits data available. Those studies that involved implementation of systems by motor carriers are discussed below. The remainder of the studies were either evaluations of systems implemented by, or discussions of benefits for, government agencies only.

Table 1. Summary of ITS/CVO Benefits Data Available

Measure	**Data Available**
Crashes	Anecdotal
Fatalities	Predicted
Time	Measured, Predicted
Throughput	None
Cost	Measured, Anecdotal, and Predicted
Customer Satisfaction	Measured, Predicted

Source: (Proper and Cheslow 1997)

There has been very limited research conducted on specific safety benefits of particular technologies to commercial vehicle companies. One major cost/benefit study conducted by the American Trucking Associations Foundation examined benefits to commercial vehicle companies in each of six ITS/CVO categories. However, this study only measured benefits in terms of labor cost reductions, and did not consider benefits of increased efficiency or safety (American Trucking Associations 1996). The project surveyed motor carriers and technology vendors to estimate benefits as well as costs of different ITS/CVO technologies. The results of the study in terms of each of the six commercial vehicle operations user services are as follows.

In the Commercial Vehicle Administrative Processes area, for carriers with more than 10 power units which have regional or national operations, the expected reduction in administrative compliance costs outweigh the costs of participation by at least four to one. There were not enough responses from carriers with less than 10 power units that were capable of Electronic Data Interchange to estimate the benefit/cost ratios for this group (American Trucking Associations 1996).

In the Electronic Clearance area, benefits in terms of reduced cost of driver time are only assumed to apply to motor carriers whose driver settlements are time-based. This assumption efficiently eliminates the majority of truckload carriers that predominantly pay their drivers on a per-mile basis, from the analysis. For those carriers who pay drivers based on hours worked, the benefits of electronic clearance for carriers of all sizes outweigh the costs by at least two to one (American Trucking Associations 1996).

Similarly, in the Automated Roadside Safety Inspection area, the benefits measured are assumed to only accrue to those companies that pay drivers on a time basis. The two areas of benefit examined were reductions in the time to undergo a roadside safety inspection and in the time to complete hours-of-service log books and trip reports, both through on-board computers or electronic log books. The calculated benefit/cost ratios for all sizes of carriers in this area were at least 1.3:1 (American Trucking Associations 1996).

In the area of On-Board Safety Monitoring, consisting of collision avoidance and on-the-road monitoring of drivers and vehicles, benefit to cost ratios in this study only considered the latter component and ranged from only 0.02:1 to 0.49:1. These low ratios are because the only benefits considered were those associated with reduced labor costs of regulatory activities and other potential benefits of the system were not taken into account (American Trucking Associations 1996).

When considering the Hazardous Material Incident Response area, benefits exceed costs for carriers with more than 10 power units with a ratio of at least 1.1:1. As with Electronic Clearance, there were not enough EDI-capable small carriers in the survey responses to estimate benefit/cost ratios for this group (American Trucking Associations 1996).

Finally, in the Freight Mobility area, since this is primarily a private sector activity, the study does not give benefit/cost ratios using the same criteria as the other user service areas. Instead, it simply states that there are many examples of improvements in carrier operating efficiency and safety within this area, with associated benefit/cost ratios of up to five to one (American Trucking Associations 1996).

Some of the limitations of the study, which become opportunities to improve the analysis in future studies, include the following: (1) the estimates are based on potential operating parameters for programs which are not implemented, (2) each user service is examined independently and not in an integrated framework, (3) benefits are only defined in terms of labor cost reductions and *do not include benefits related to increased* *efficiency or safety,* and (4) the labor cost reductions are estimated by the motor carriers through the survey and are assumed to be reasonable (American Trucking Associations 1996).

It is interesting to note that even with the conservative estimate of benefits in this study, and the use of actual costs of the technologies, almost all of the user service areas have benefit/cost ratios greater than one to one.

In terms of benefit/cost analyses of ITS/CVO for the motor carrier industry, even with its limitations, the above study is the most thorough to date. The majority of other studies related to the benefits of ITS/CVO approach the analysis from the viewpoint of the benefits to state agencies.

Expanding on the ATA study, Maze et. al (1998) examined the benefits to commercial vehicle companies specifically in the area of electronic clearance. However, this study only considered the direct benefits of reduced delay and fuel consumed by compliant trucks that are electronically cleared to bypass weigh stations, and did not consider safety benefits.

The only study to date that examined safety benefits simply *predicted* benefits of reductions in fatalities due to ITS/CVO technologies. Various scenarios of fatal involvement reduction ratios and market penetration rates of technologies were examined to arrive at a benefit range of an 8-27% reduction in fatal involvements. The study did not examine specific technologies and did not link technologies to specific companies. It simply used an estimated market penetration rate for all the ITS/CVO services and an arbitrary fatal involvement reduction factor to determine the potential reduction in fatalities (Evanco 1997).

Anecdotal evidence exists regarding the safety benefits of certain technologies. For example, one major commercial vehicle company, Schneider National, claims that its on-board computer systems have helped to reduce its accident rate by 35 percent through the ability to track drivers' hours and speed (Cohen 1995). However, it is not known if this benefit would translate to other companies or to other measures of safety.

In terms of crash reduction, the evidence thus far is only anecdotal that in-vehicle or roadside ITS technologies that identify drivers and vehicles at high risk, and the associated improvement of traffic flow near enforcement areas, will reduce the number of crashes.

In the area of time benefits of ITS/CVO, the use of communication and advanced vehicle monitoring technologies have illustrated substantial savings. Some of the companies that have measured and reported their time benefits associated with these technologies are Schneider National, Trans-Western Ltd, Frederick Transport, and Best Line. For example, Schneider reports in a 1992 study that they have been able to save about two hours a day by eliminating driver check-in telephone calls. Similarly, Best Line estimates about a $10,000 savings a month by eliminating driver waiting time to talk with dispatchers (Morlok and Hallowell 1989).

In addition, a 1997 simulation study predicted time savings at weigh stations both for transponder-equipped vehicles as well as for non-equipped vehicles. Obviously, transponder-equipped vehicles permitted to bypass the station save 100% of the delay time. However, as the percent of transponder-equipped vehicles rises, and queue lengths shorten, non-equipped vehicles can also benefit and save up to an average of eight minutes at the station (Proper and Cheslow 1997).

In the area of cost reduction, there are anecdotal, measured, and predicted benefits. Anecdotal evidence was provided by carriers involved in an operational test of commercial vehicle administrative processes in 1996. They estimated a potential to reduce costs 33 to 50 percent for International Fuel Tax Agreement and International Registration Plan reporting. Measured cost reductions were once again provided by the same carriers mentioned above (obviously, time savings translate into cost reductions). Some of the cost reductions were specifically due to the increase in loaded mileage of 9 to 16 percent, and subsequent decrease in operating costs of $0.12 to $0.20 per truck mile. In addition, decreases in driver turnover were also reported resulting in another significant cost savings. The majority of the predicted cost benefits are from the 1996 ATA Foundation study discussed previously, however one additional 1995 study did predict some cost savings from the use of real-time traffic diversion of carriers which resulted in a productivity improvement of 6 percent (Proper and Cheslow 1997).

With regards to customer or user satisfaction, once again the measured benefits here were by the same motor carriers as above with noted benefits of increased loaded miles, improved customer service, decreased driver turnover, and reports of 17 percent more shipments and 4 percent fewer cancellations due to ITS technologies (Morlok and

Hallowell 1989). In addition, in a 1995 study of 1,500 commercial vehicle drivers, almost 90 percent viewed some or all of the available CVO services favorably (Proper and Cheslow 1997).

In addition to the above measures, still another benefit noted of ITS/CVO is emissions and fuel consumption reductions. A 1997 study has stated that there is a fuel savings of 0.05 to 0.18 gallons per avoided stop with a pre-clearance system such as in Advantage I-75 (Proper and Cheslow 1997).

As mentioned previously, nothing has been done to date in measuring the benefits of ITS/CVO in the throughput area (i.e., the number of people, vehicles, or goods moved per unit of time), although this has been alluded to in the evidence of increases in loaded miles. Another area for investigation may be the effect on the reliability of transit times and the associated benefits of this. However, most notably, there has been little investigation into any direct link between specific technologies and commercial vehicle safety.

Expanding the literature review to consider all types of vehicles and potential safety benefits related to technologies considered in the present study, a literature search reveals very few findings. The most numerous articles were related to cell phone technology with the main findings that the use of a cell phone while driving resulted in delayed reactions and more accidents (see for example Strayer et al 2006; and Beede and Kass 2006). In addition, these articles demonstrated how other distractions from various in-vehicle systems in general can contribute to delayed reaction times.

2.3 Inventory-Theoretic Models to Illustrate Benefits

Although previous researchers have used several methodologies to attempt to estimate the benefits of commercial vehicle-related technologies, not one has considered borrowing from the literature regarding logistics. As noted by the Council of Supply Chain Management Professionals, logistics management is defined as “that part of Supply Chain Management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements” (Council of Supply Chain Management Professionals). Logistics provides a holistic system framework for decision making which considers transportation, inventory, warehousing, materials handling, packaging, etc., and the associated cost and service tradeoffs in every area from any changes that are made in the system. Thus, this seems like an obvious area to research when considering the impact of commercial vehicle-related technologies on a company.

One possible reason that there has been limited research completed regarding the benefits of technology on safety and service from a supply chain perspective is that these benefits are difficult to quantify. For example, if a commercial vehicle company implements electronic logbooks, and as a result has five percent fewer drivers placed out-of-service during roadside inspections than carriers without electronic logbooks, how does the carrier measure this impact on the total logistics costs of the company it serves?

The majority of the costs in the supply chain can be attributed to inventory and transportation. Without the proper inventory available, a company may lose sales and experience a decline in customer satisfaction. This must be balanced against the increased costs of warehousing, insurance, obsolescence, and other costs associated with carrying excess inventory. The amount of inventory needed is related to the method(s) of transportation used. Transit time, reliability, and the amount of loss and damage during the transportation affect the amount of excess inventory (i.e., safety stock) required. A company may choose a lower cost method of transportation, but this needs to be balanced against the increased cost of the inventory needed.

In fact, one particularly applicable article illustrates how carriers can use information regarding transit time and reliability when bargaining with shippers regarding rates. As stated in the article, "Because the carrier must recover these resource costs, the carrier must be able to estimate the benefit (reduction in distribution costs) to the shipper/receiver in order to determine what the shipper/receiver is able to pay for the improved service" (Allen et al 1985). This is exactly what commercial vehicle companies considering certain technologies need to do. They need to estimate the benefit that the new technology will provide to their customer (the shipper) and determine what the shipper is willing to pay for this improved service. In addition, the carrier could also estimate the additional market share that this improved service could provide them.

The article illustrates the use of an inventory-theoretic model and the associated total distribution costs under differing means and variances of travel times. Placing these into a matrix easily illustrates how much a shipper may be willing to trade off to achieve increased reliability and/or transit time (Allen et al 1985). As an example, refer to Table 2. In the extreme case that the mean travel time is reduced from 5 days to 2 days and the variance of the travel time is reduced from 0.6 to 0.0, the total distribution cost to the shipper is reduced by $58.86.

Table 2. Example of Total Distribution Cost for Differing Means and Variances of Travel Time

	Variance						
Mean	**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
2	$648.63	$657.11	$665.47	$673.64	$681.81	$686.79	$689.34
3	$656.72	$665.54	$674.17	$682.81	$687.81	$691.40	$695.00
4	$666.35	$675.14	$683.84	$688.22	$692.52	$696.83	$701.14
5	$676.82	$683.41	$688.28	$693.08	$697.88	$702.69	$707.49

Source: (Allen et al 1985)

This idea is further illustrated by Tyworth and Zeng (1991) in a more recent article which extends and improves on the analysis. As detailed in the paper, the expected total annual logistics cost (ETAC) can be expressed as the sum of transportation, holding, ordering, and shortage costs as follows:

$$ETAC(s,Q) = \left[f(Q)(1-d)R\frac{w}{100} \right] + \left[\mu_T \mu_D \bullet V \bullet Y + \left(\frac{Q}{2} + s - \mu_X \right) V \bullet W \right] + \left[A\frac{R}{Q} \right] + \left[ES \bullet B_2 V \frac{R}{Q} \right]$$

where f(Q) = continuous functional relationship between the freight rate and lot size,

d = percentage discount offered by the carrier,

R = annual demand,

w = weight,

μ_T = mean transit time,

μ_D = mean demand per period,

V = value or standard cost of inventory item,

Y = annual carrying cost factor for in transit stock,

Q = fixed order quantity,

s = reorder point,

μ_X = mean lead-time demand,

W = annual carrying cost factor for warehouse stock,

A = order processing cost,

ES = expected shortages per replenishment cycle, and

B_2 = pre-specified fraction of unit value charged per unit short.

The obvious objective is to minimize this function by changing the decision variables *s* (the reorder point) and *Q* (the order quantity). Using this type of formulation, one could easily determine the effect that changes in the mean and/or the variance of the transit time could have on the total annual logistics costs. Tyworth et al (1998) has also previously illustrated how this formulation can be readily solved using popular spreadsheet programs.

2.4 Known Factors Related to Commercial Vehicle Company Safety

Prior research has illustrated that there are several commercial vehicle company characteristics that relate to safety. For example, larger companies (based on number of vehicles) have lower crash rates than smaller companies, and private carriers have lower crash rates than for-hire carriers (Moses and Savage 1994). In addition, profitability of a company has been illustrated to be associated with crash rates, with more profitable companies having lower crash rates (Bruning 1989). Unfortunately, finding measures of profitability for a company can be difficult.

Company policies in general — such as driver recruitment and training procedures, and driver pay — can also have a significant impact on safety (see for example, Murray and Whiteing 1995; or Rodriguez, Targa, and Belzer 2006). In addition, research has shown that even the types of roads that a company's trucks normally travel can affect the safety of the company. In general, more crashes occur on undivided roads rather than interstate highways (Daniel and Chien 2004).

When you consider any accident, there are normally a number of factors that may have related to that accident - namely, those related to environment, roadway, the vehicle, and/or the driver. Some of these such as the environment are beyond a company's control, while others such as the vehicle or driver can be mitigated with good maintenance and training practices. It is anticipated that the right technology, successfully adopted, can also assist in certain areas related to maintenance or training, and this will be discussed more in the specific technology sections in the next chapter.

CHAPTER 3. HYPOTHESES

As discussed in the previous chapter, according to Everett M. Rogers' landmark work (1995), there are five main attributes of innovations: (1) relative advantage, (2) compatibility, (3) complexity, (4) trialability, and (5) observability. The theory states that higher ratings on all factors, except complexity, lead to greater adoption of the technology or innovation.

One main question of interest for the present study is the applicability of this theory to the area of technology adoption and safety. Given that a particular technology either advertises that it will impact safety or has been demonstrated to impact safety in some way, do the ratings in each factor influence not only the adoption of the technology, but its safety impact on the company as well? As discussed in this chapter, depending on the technology, the safety impact may be a positive or negative impact. Restated, the first main hypothesis for this study is as follows.

Hypothesis 1: For companies that have implemented a technology, those technologies that have one or more technology adoption factors with a high positive rating will have higher adoption rates, and more of a safety impact for the company, than technologies with no or fewer factors with high positive ratings.

Hypothesis 1 can be summarized by the following diagram:

	Low positive ratings or high positive rating in no or one factor	High positive rating in two or three factors	High positive rating in four or five factors
Lower adoption / safety impact			
Moderate adoption / safety impact			
Higher adoption / safety impact			

3.1 Hypotheses Specific to the Commercial Vehicle Industry

The commercial vehicle industry is important to society, and there are many new technologies available to this industry. Although many of the technologies for commercial vehicle companies appear to have the potential to impact safety and service, the main question is why? What is it about a particular technology that leads it to have a greater impact than another? Which technologies have had the greatest impact on safety and service in the commercial vehicle industry and why? What factors regarding the company or the technology lead to this impact? How do / can companies measure this impact?

There are many types / classifications of commercial vehicle companies, such as:

- Size (number of vehicles and/or drivers);
- Type of operation (for hire or private);

- Cargo carried (general, household goods, metal, motor vehicles, produce, liquids / gases, livestock, construction, etc.);
- Mileage per year;
- Truckload or less-than-truckload;
- Length of time in operation; and
- Profitability.

Different commercial vehicle companies have different types of operations, different business models, and thus different technology needs.

Because of the different technology needs of commercial vehicle companies, it is expected that different types of companies will have different ratings on each of the five attributes for a technology. Furthermore, it is anticipated that companies with higher ratings on the five attributes will have better adoption or acceptance of the technology. Depending on the particular technology, this in turn could lead to a greater (or worse) effect in both safety and service of the company versus those companies with technologies that have lower adoption or acceptance ratings.

3.1.1 Description of Technologies for Commercial Vehicle Operations

Presently, the majority of technologies available for commercial vehicle operations can be classified under the name of Intelligent Transportation Systems or ITS. As defined in the National ITS Program Plan:

> Despite the fact that the United States has one of the best surface transportation systems in the world, mobility is declining and safety

> remains a serious problem. Inefficient movement of vehicles reduces productivity, wastes energy, increases emissions, and threatens the quality of life we enjoy. The continued development and maintenance of a safe, efficient, environmentally responsible transportation system is vital to the social and economic health of the nation. Intelligent Transportation Systems (ITS) apply advanced and emerging technologies in information processing, communications, control, and electronics to meet surface transportation needs. ITS, formerly called Intelligent Vehicle-Highway Systems (IVHS), provide a means to address current problems, as well as anticipate and address future demand through an intermodal, strategic approach to transportation. While ITS technology alone cannot solve our problems, it can enable us to re-think our approach to problem solutions, as well as to make current activities more efficient (Euler and Robertson 1995).

The IVHS (now ITS) program was established by the Intelligent Vehicle Highway Systems Act within the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). The ISTEA authorized $660 million to research, develop, and test ITS applications. Overall, there are more than 400 projects nationwide to test and deploy new ITS technologies (Reed, Goehring, and Pattarozzi 1996). The specific goals of ITS established by the ISTEA are to:

- Improve the safety of the nation's surface transportation system;
- Increase the operational efficiency and capacity of the surface transportation system;
- Reduce energy and environmental costs associated with traffic congestion;
- Enhance present and future productivity;

- Enhance the personal mobility and the convenience and comfort of the surface transportation system; and
- Create an environment in which the development and deployment of ITS can flourish (Euler and Robertson 1995).

With these goals in mind, seven main areas consisting of 29 “user services” were conceptualized. These user services are illustrated in Table 3 and are products and services that either have been or may be developed in response to the needs of individuals and organizations. These services and definitions are subject to change over time (Euler and Robertson 1995).

The ITS technologies which are currently and potentially available specifically for commercial vehicle operations (CVO) are illustrated under the fifth area in Table 3. The main focus of these technologies is to: (1) improve fleet management and freight mobility for the private sector, and (2) make government and regulatory functions more efficient. The vision for the ITS/CVO program is: “Assisted by advanced technology, trucks and buses will move safely and freely throughout North America” (Euler and Robertson 1995).

As shown in Table 3, the ITS/CVO technologies are classified into six categories. These are briefly described below with a listing of the specific technologies that would be used by commercial vehicle companies in each area.

Table 3. ITS User Services

Area	**User Services**
1. Travel and Transportation Management	1. En-Route Driver Information 2. Route Guidance 3. Traveler Services Information 4. Traffic Control 5. Incident Management 6. Emissions Testing and Mitigation
2. Travel Demand Management	1. Demand Management and Operations 2. Pre-Trip Travel Information 3. Ride Matching and Reservation
3. Public Transportation Operations	1. Public Transportation Management 2. En-Route Transit Information 3. Personalized Public Transit 4. Public Travel Security
4. Electronic Payment	1. Electronic Payment Services
5. Commercial Vehicle Operations	1. Commercial Vehicle Electronic Clearance 2. Automated Roadside Safety Inspection 3. On-board Safety Monitoring 4. Commercial Vehicle Administrative Processes 5. Hazardous Materials Incident Response 6. Freight Mobility
6. Emergency Management	1. Emergency Notification and Personal Security 2. Emergency Vehicle Management
7. Advanced Vehicle Control and Safety Systems	1. Longitudinal Collision Avoidance 2. Lateral Collision Avoidance 3. Intersection Collision Avoidance 4. Vision Enhancement for Crash Avoidance 5. Safety Readiness 6. Pre-Crash Restraint Deployment 7. Automated Highway System

Source: Euler and Robertson 1995

3.1.1.1 Commercial Vehicle Electronic Clearance

The commercial vehicle electronic clearance service allows commercial vehicles equipped with transponders to be electronically checked for size and weight requirements, operating credentials, and safety while at highway speeds. If all is satisfactory, the vehicle is cleared to bypass the weigh station or port-of-entry.

This service had its beginnings through both the Advantage I-75 and the Heavy Vehicle Electronic License Plate, Inc. (HELP, Inc.) projects. The Advantage I-75 project cleared vehicles through weigh stations along Interstate-75 which runs from Florida through the Midwest into Ontario; while the HELP, Inc. project, through what is termed PrePass, clears vehicles in many western and Midwestern states (Euler and Robertson 1995).

The only technology in this area required for a commercial vehicle company is a transponder for each of their vehicles.

Electronic clearance technology is expected to rate high on relative advantage (it surpasses the current practice of needing to stop at each toll booth and weigh station), high on compatibility (it works with every existing type of vehicle and there is uniformity across toll booths and weigh stations), low on complexity (it is simple to install and use), high on observability (company representatives see the use of transponders on a daily basis wherever they travel), and high on trialability (a company can install transponders on as few or as many vehicles at any time). Thus it is expected that the adoption rate for this technology will be high, and the technology will be used to a greater degree in the company.

This use of electronic clearance technology has the potential for reducing accidents due to slowing down to enter the queue for weigh station / toll booth or merging back into the stream of traffic when exiting the weigh station / toll booth. With transponders and ability to by-pass weigh station and/or toll booths, these accidents will be reduced.

In addition, carriers must meet and maintain safety requirements in order to achieve and keep bypass privileges. Thus, carriers with electronic clearance technology should be safer than the rest of the population (in terms of both accidents and safety violations).

However, the use of transponders also has the potential for a negative safety impact. For example, if a toll gate is set-up for both transponder users and non-transponder users to use the same gate, this may cause accidents due to speed differentials. In addition, companies with transponders to bypass weigh stations are most likely not receiving the same amount of safety inspections than those companies that must pull into every weigh station. Therefore, more of their vehicles may have safety defects that go unnoticed and potentially could cause more accidents.

3.1.1.2 Automated Roadside Safety Inspection

The goal of the automated roadside safety inspection service is to provide more selective as well as quicker roadside inspections of commercial vehicles. This is accomplished through the provision of safety data to inspectors at the roadside and the use of sensors and diagnostic equipment (Euler and Robertson 1995). As an example, the author was involved in the development and implementation of the Inspection Selection System which recommends vehicles and drivers for inspection based on their company's prior safety performance and history of inspections. This system is currently in use throughout the United States and has proven to be very effective at targeting unsafe carriers for inspection (Lantz, Blevins, and Hillegass 1997).

The technologies in this area are designed for enforcement officials, and there are no specific technologies required for commercial vehicle companies. Thus, these technologies are not analyzed in the present study.

3.1.1.3 On-Board Safety Monitoring

The objective of the on-board safety monitoring service is to enable the ability to continuously monitor the driver, the vehicle, and the cargo, and to make notification if an unsafe situation occurs (Euler and Robertson 1995).

Potential technologies for commercial vehicle companies to use in this area include: on-board computers, electronic logbooks, and collision avoidance systems.

The ratings for on-board safety monitoring technologies will be more dependent on the company. It is anticipated that they will be rated high on relative advantage (it surpasses the current practice of no monitoring), high on compatibility (they should work with every existing type of vehicle), moderate on complexity (based on perceived ease of use), moderate on observability (these are not so easily noticed), and high on trialability (a company can install an on-board technology on as few or as many vehicles at any time). Thus it is expected that the adoption rate for on-board technology will be moderate, and the technology may be used with a limited degree of success in the company.

This use of on-board technology should better assist in monitoring the vehicle or driver so that the carrier or driver is notified when there is a problem before there is an accident or safety violation. Thus, carriers with successful adoption and use of this technology may be safer than the rest of the population (in terms of both accidents and safety violations). However, as was discussed previously, there may also be issues related to whether the on-board technology causes a distraction to the driver that may result in increased reaction times and increased accidents.

3.1.1.4 Commercial Vehicle Administrative Processes

The commercial vehicle administrative processes service is designed to allow companies to purchase needed credentials, as well as to collect and report fuel and mileage tax information electronically (Euler and Robertson 1995).

The only technology needed for a commercial vehicle company in this area is access to the Internet. However, because this technology is used for administrative processes, it is not analyzed with the present study.

3.1.1.5 Hazardous Materials Incident Response

Technology in this area is intended to provide emergency personnel immediate information regarding the type and quantity of hazardous materials present at the scene of an incident. Technologies in this area are designed for use by emergency personnel, and there are no specific technologies required for commercial vehicle companies (Euler and Robertson 1995). Thus, these technologies are not analyzed in the present study.

3.1.1.6 Freight Mobility

This area includes technology to provide the ability for information and communication exchange between drivers, dispatchers, and transportation providers. It enables companies to take advantage of real-time traffic and vehicle location information (Euler and Robertson 1995).

Potential technologies for commercial vehicle companies in this area include: mobile communications, computer aided routing and dispatching, and maintenance tracking software.

It is anticipated that freight mobility technologies will be rated high on relative advantage (it surpasses the current practice of needing to stop to locate and perhaps wait for a pay phone or manually determining routes / schedules), moderate to high on compatibility (they should work with every existing type of vehicle, but there may be some dependence on the existing information systems at the company), low to moderate on complexity (based on perceived ease of use), moderate to high on observability (these technologies may or may not be easily noticed), and moderate to high on trialability (a company may be able to install these technologies in phases or may need to install it company-wide all at once). Thus it is expected that the adoption rate for freight mobility technologies will be moderate, and thus may be used with a more limited safety impact to the company.

Freight mobility technologies allow drivers and dispatchers to be in constant communication, so drivers are able to notify the company if an unsafe condition occurs; allow for better scheduling to avoid drivers running over hours; and/or allow for better tracking of vehicle regularly scheduled maintenance and defect checking. This should result in fewer safety violations and/or accidents and thus, carriers with successful adoption and use of this technology may be safer than the rest of the population. However, research has shown, in particular, that the use of cell phone technology while driving can lead to driver distraction and more accidents. Thus, unless the company has a specific policy regarding this that is followed by its drivers, the use of certain freight mobility technologies could potentially increase accidents.

This discussion leads to two main hypotheses specific to the commercial vehicle industry. Hypothesis 2 simply states that the implementation of the technology will have an effect on safety, while hypothesis 2a states that the successful adoption of the technology will have an effect on safety.

Hypothesis 2: The implementation of technologies related to electronic clearance, on-board safety monitoring, and freight mobility will impact the safety of the company (in terms of accidents and safety violations).

Hypothesis 2a: The successful adoption of technologies related to electronic clearance, on-board safety monitoring, and freight mobility will impact the safety of the company (in terms of accidents and safety violations).

CHAPTER 4. RESEARCH OBJECTIVES AND METHODOLOGY

Because of the importance of safety, and the potential benefits for both the general public and the commercial vehicle industry of improving safety, the main goal of this study is to identify those commercial vehicle-related technologies that, through successful adoption, have had a positive impact on the safety of motor carrier companies. With this information, an estimate of specific benefits to partners in the supply chain can be determined. As described in the introductory chapter, the benefits to companies of improving safety, besides the obvious public benefit, include such things as lower overall costs, including insurance rates, increased productivity, and increased business. It is anticipated that this information could also be used by the FMCSA and motor carrier companies to aid them in implementing technologies that will be of the greatest benefit to both the public and the industry.

4.1 Research Design

The main purpose of this study is to determine which technologies, through successful adoption, have had a positive impact on the safety of commercial vehicle companies.

To accomplish the main objective, hypothesis testing is utilized. The specific hypotheses were detailed in Chapter 3. Each type of technology and its associated adoption factors are tested separately. In addition, possible moderating variables are tested, including the size and type of company and how long the technology has been in use.

It was anticipated, before any analysis was completed, that the technologies mainly related to the driver will have a positive effect on driver out-of-service rates. For example, it was expected that the use of on-board safety monitoring technologies, such as electronic logbooks for monitoring driver hours of service, will result in a decrease in driver related out-of-service order violations. Similarly, technologies related more to the vehicle should have a positive effect on vehicle out-of-service rates. For example, the use of on-board computers for vehicle diagnostics should result in lower vehicle related out-of-service order violations.

However, although a driver (or vehicle) related technology was expected to relate to lower driver (or vehicle) related out-of-service violations, it was examined whether the technology will have an effect on both types of violations.

Possible moderating variables for this analysis include how long the technology has been in use, as well as the size and type of carrier. It was expected that for companies that have had a technology in place for a greater length of time, they will most likely have high ratings in the adoption factors, and there will be a more pronounced effect on their out-of-service rates. It was not known a priori whether size or type of carrier will have a moderating effect on the relationship between technology and out-of-service rates, but this information was collected and tested for any effect. Based on past research, it is known that larger and/or private companies are generally safer (have lower crash rates) than smaller and/or for-hire companies.

Data regarding technology use and adoption factors was gathered at one time, thus the study is cross-sectional, with the unit of analysis at the company level. In addition, since there are many factors that influence safety, this study is correlational in nature rather than causal. The intent is to discern if certain technologies, successfully implemented, are associated with lower accident and out-of-service violation rates for the companies.

4.2 Research Methodology

There currently exists a nationwide database of interstate commercial vehicle companies maintained by the U.S. Department of Transportation Federal Motor Carrier Safety Administration (FMCSA) that contains the safety-related information relevant for this project. This database is continuously updated and readily accessible to the author.

The obvious dependent variable of interest for this project is the safety of commercial vehicle companies. Not so obvious, however, is exactly how to measure safety. Normally, one defines safety by accidents. However, accidents are caused by many factors that may not necessarily be related to the company itself (i.e., the weather, road conditions, other drivers' actions, etc.). In addition, the only database that links accidents to specific motor carriers is the one maintained by the FMCSA, and they are the first to admit that there are serious under reporting problems in the data. The FMCSA receives information from the states each year regarding approximately 100,000 recordable accidents; but the belief is this is about 50,000 under what it should be. Also, some of the accident data submitted is inaccurate and/or incomplete (Craft 2004). Therefore, an additional measure or “proxy” of safety should be evaluated as well. One possible additional measure is the company’s roadside inspection out-of-service rate.

One of the main commercial vehicle safety activities of the FMCSA is to conduct roadside inspections. Roadside inspections follow a standard known as the North American Standard which was developed by the Commercial Vehicle Safety Alliance in cooperation with the Federal Highway Administration. Inspections involve an examination of vehicles, drivers, and hazardous material cargo; and focus on critical safety regulations. They include provisions for placing vehicles and/or drivers out-of-service (OOS) if unsafe conditions are discovered. These problems must be corrected prior to the continuation of a trip (Sienicki 1997).

Data obtained from roadside inspections of commercial vehicles are input, or uploaded from a computer, by states locally into an information system termed SafetyNet. The states then transmit relevant data for carriers electronically to the Motor Carrier Management Information System (MCMIS) at FMCSA headquarters.

There are two reasons to justify the use of the out-of-service rates as a proxy measure of safety. First, these rates have been illustrated in previous research to be significantly positively correlated with accident rates, i.e., companies with higher out-of-service rates also tend to have higher accident rates (Lantz 1993). Second, companies and drivers are required to be knowledgeable of the regulations, and to examine their equipment before every trip to ensure that there are no violations. Therefore, when a vehicle or driver violation is found during a roadside inspection, it is a direct reflection on the company. Thus, the higher the number of out-of-service orders a company has, the more unsafe that company is likely to be.

Specifically, the possible dependent variables of interest are the number of accidents and the number of driver and vehicle out-of-service inspections. The data for these dependent variables are readily available from the FMCSA.

The other variables of interest include which technologies, if any, the company is using, how long the technology has been in place, as well as demographic characteristics such as the size of the company (measured by the number of power units), whether the company is truckload or less-than-truckload, or private or for-hire. In addition, information is needed regarding the innovation diffusion / technology adoption factors for various technologies and companies. Unfortunately, no database currently exists that has this information. Thus, a survey of a stratified random sample of commercial vehicle companies was conducted to obtain the necessary data.

The full survey for this study, along with the cover letter and the implied informed consent form, can be found in Appendix A. For each of the technology adoption factors, two questions were asked to form a construct for each technology adoption factor for each technology. As detailed in the full survey in Appendix A, the questions for each technology adoption factor were phrased as follows:

Relative Advantage

1 - Using [the technology] enhances our efficiency.

2 - Using [the technology] makes our job/work easier.

Compatibility

1 - I think [the technology] fits well with the way we work.

2 - I think [the technology] fits into our lifestyle.

Complexity

1 - Learning to interact with [the technology] was easy for us.

2 - It was easy for us to become skillful at using [the technology].

Trialability

1 - We were able to try out [the technology] on a limited basis before we decided to fully implemented it.

2 - We were able to implement [the technology] in phases rather than all at once.

Observability

1 - We were able to observe other companies using [the technology] before we decided to try it.

2 - Once in use, our employees and/or customers could readily see and understand why we chose to implement [the technology].

One of the main differences between this survey and surveys in prior research is that, with the present one, there is the ability to link the motor carrier response regarding their use of technology with their safety data. In addition, the sample for the current study was drawn from the FMCSA database, whereas the sample for the ATA study, for example, was limited to members of the American Trucking Associations and the National Private Truck Council.

Prior studies have used the survey approach to acquire information from commercial vehicle companies regarding use and perception of information technologies (see for example, Bigras and Roy, 2000; Regan and Golob, 1999; McCord and Hidalgo, 1996; ATA Foundation, 1996). In the previous studies, response rates from commercial vehicle companies ranged from 10 percent to 23 percent.

Although it would have been preferable to survey the entire population of over 600,000 carriers that are contained in the FMCSA database, this was not feasible from a time or cost perspective. In addition, not all of these carriers have enough safety data for the analysis. The FMCSA has a standard for using the results of at least three roadside inspections on a carrier in a 30-month period before calculating the inspection out-of-service rate. Using this standard, there are still more than 170,000 carriers in the database available for analysis. Because this is still a very large number, a sampling procedure was used.

Since it was desired to receive information regarding technologies used by all sizes of carriers, a stratified random sample was used to ensure representation from all size groups in the survey. The distribution of the sizes of the carriers in the sample taken August 2005 (based on the number of power units) is displayed in Table 4.

Table 4. Distribution of Carriers in the Sample

Size of Carrier	Number in Sample
Missing power unit information	2,081
1 power unit	47,378
2-6 power units	71,631
7-15 power units	28,451
16-63 power units	18,283
64-200 power units	3,919
201-1,000 power units	1,325
More than 1,000 power units	231
Total	173,299

The sample size required to estimate the population mean Φ with a bound *B* on the error of estimation is given by (Scheaffer et al 1990):

$$n = \frac{\sum_{i=1}^{L} N_i^2 \sigma_i^2 \big/ w_i}{N^2 D + \sum_{i=1}^{L} N_i \sigma_i^2}$$

where L = the number of strata,

N_i = the number of sampling units in stratum i,

σ_i = the standard deviation for stratum i,

w_i = the fraction of observations allocated to the ith stratum,

N = the number of sampling units in the population, and

$D = B^2/4$

The Neyman allocation method, which takes into account both the total number of elements in each stratum as well as the variability, calculates w_i above as follows (Scheaffer et al 1990):

$$w_i = \frac{N_i \sigma_i}{\sum_{i=1}^{L} N_i \sigma_i}$$

Using the largest standard deviation of the dependent variables of interest, which in every stratum was the overall vehicle violation rate, and a bound on the error of estimation of 0.2, reveals the sample size requirement for each stratum. However, it was decided that each stratum should have a minimum of 30 observations, and that each sample size should be increased five times to account for an average response rate of 20 percent in survey research. With these adjustments, the sample sizes and the number of surveys needed for each stratum are illustrated in Table 5.

Table 5. Sample Size and Number of Surveys Needed for Each Stratum

Size of Carrier	Sample Size Needed	Number of Surveys
Missing power unit information	3	150
1 power unit	60	300
2-6 power units	87	435
7-15 power units	28	150
16-63 power units	14	150
64-200 power units	2	150

Size of Carrier	Sample Size Needed	Number of Surveys
201-1,000 power units	1	150
More than 1,000 power units	0	231
Total	195	1,716

A draft survey was distributed to a sample of carrier representatives for suggestions and revisions, and then the final surveys were distributed by randomly selecting carriers from each stratum defined in the sampling procedure. Included with the survey was a cover letter explaining the study, an implied informed consent form, information about where the commercial vehicle company can obtain the results once the study is completed, as well as a postage-paid return envelope.

Once the surveys were returned and the data entered, this database was combined with the safety data for each commercial vehicle company from the FMCSA database. Appropriate regression models were developed to analyze the effect of the technology adoption factors and various technologies on safety while controlling for the moderating variables. Safety was measured using accident rates as well as inspection out-of-service rates.

4.3 Contribution of Research

Because of the importance of safety, and the potential benefits for both the general public and the commercial vehicle industry of improving safety, the main goal of this project is to identify those technologies that, through their successful adoption, have had a positive impact on the safety of commercial vehicle companies. With this information, an estimate of specific benefits to companies and their customers can be determined.

The benefits to companies of improving safety, besides the obvious public benefit, include such things as lower overall costs, including insurance rates, increased productivity, and increased business. It is anticipated that the information discovered in this project could be used by commercial vehicle companies to aid them in implementing technologies that will be of the greatest benefit to both them and their customers. In addition, the information could be used by the FMCSA to help them to target their efforts towards advocating the implementation of technologies that have the greatest potential safety impact.

To date, no previous research has been conducted regarding this very important link between particular technology implementation and commercial vehicle safety. Also, no research has been completed examining the benefits to the company and their customers with respect to improved safety.

4.4 Summary

This chapter outlined the specific research objectives, design, and methodology for the present project. A combination of survey research and regression analysis will be conducted to accomplish the overall objective of identifying those technologies that have a positive impact on safety; and measuring this impact in terms of both safety and service for partners in the supply chain. The contribution of this research was also discussed.

CHAPTER 5. ANALYSIS AND RESULTS

The commercial vehicle company technology surveys were distributed via regular mail, as well as electronically via email if available, to the 1,716 carriers August 2005. Ten surveys were returned as undeliverable. In addition, at least one company who had received five surveys for each of their unique divisions called to state the survey was not applicable to them. Of the remaining surveys, 97 were returned for an effective response rate of approximately six (6) percent. The distribution of the size of companies that completed and returned the survey is presented in Table 6.

As presented in Table 6, there is representation from each size stratum surveyed, and in the same approximate percentages of the total as the distribution of companies that were mailed the surveys. In addition, an analysis of the dependent variables of interest — the accident rate, the driver out-of-service rate, and the vehicle out-of-service rate — reveals similar distributions between all companies that were mailed the survey and those who responded. The accident rates, driver out-of-service rates, and vehicle out-of-service rates for the companies that responded to the survey ranged from zero (0) up to one (1); and the respective means and medians between the two groups were close. Thus, there is adequate representation in the respondents between those companies that would be classified as “more safe” versus those that would be classified as “less safe,” and non-response bias does not appear to be a concern.

Table 6. Distribution of Companies that Responded to the Survey

Size of Carrier	Number of Surveys Returned
Missing power unit information	2
1 power unit	13
2-6 power units	21
7-15 power units	7
16-63 power units	12
64-200 power units	15
201-1,000 power units	11
More than 1,000 power units	16
Total	97

Additional demographic and descriptive analyses are presented in the next section.

5.1 Demographic and Descriptive Analysis

Regarding demographic information, companies were asked how many trucks/buses, tractors, and/or trailers they operate; as well as how many drivers they use.

- The average number of trucks/buses was 66 with a range up to 2,291;
- the average number of tractors was 377 with a range up to 8,642;
- the average number of trailers was 1,470 with a range up to 24,500;
- the average number of company drivers was 642 with a range up to 11,500; and,
- the average number of independent contractors used was 122, with a range up to 1,300.

Ninety-four (94) of the companies operate primarily as truckload and three (3) of the companies are primarily less-than-truckload operation. In addition, 62 of the companies were primarily a for-hire operation and 35 primarily a private operation. Regarding the type of cargo the companies generally haul, the wide variety of responses included general freight, building materials, livestock, hazardous materials, and refrigerated products.

Finally, regarding how long the companies have been in business, the average was approximately 32 years, with a range of 3 years to 100 years.

Regarding specific technology use, freight mobility technologies were operationalized in the survey to include mobile communications (cellular phones and/or satellite), computer aided routing and dispatching, and maintenance tracking software. On-board safety monitoring technologies were operationalized in the survey to include on-board computers (for vehicle diagnostics and/or driver performance), electronic logbooks, and collision avoidance systems. Finally, electronic clearance technologies were operationalized in the survey to include transponders (for bypassing toll booths and/or weigh stations). The number of companies using each technology is as follows.

Freight Mobility Technologies

- 72 of the companies currently use cellular phones and 21 of the companies currently use satellite for communications between dispatcher and drivers,
- 39 of the companies use computer-aided routing and/or dispatching,
- 25 of the companies currently use maintenance tracking software.

On-Board Safety Monitoring Technologies

- 25 of the companies use on-board or handheld computers for vehicle diagnostics and 6 of the companies use this technology for driver performance,
- 5 of the companies currently use electronic logbooks for monitoring driver hours of service,
- 6 of the companies use collision avoidance systems, and

Electronic Clearance Technologies

- 35 of the companies use transponders for toll booths and 24 of the companies use transponders for bypassing weigh stations.

Out of the 97 respondents, 25 (26 percent) indicated they use only one of the above technologies, 50 (52 percent) indicated they use two to four of the technologies, 14 (14 percent) indicated they use five to nine of the technologies, and the remaining eight (8 percent) indicated they do not use any of the technologies.

5.2 General Hypothesis Results

As detailed in Chapter 4, for the survey, there were two questions asked to form a construct for each of the technology adoption factors. Cronbach's alpha was computed on the measures for each construct with mixed results. The constructs for relative advantage, compatibility and complexity all had Cronbach's alpha between 0.8 and 0.9 (well within the accepted range of 0.7 or above); however the Cronbach's alpha for the constructs of trialability and observability were only between the 0.3 and 0.4 range. Thus the questions related to relative advantage, compatibility and complexity were combined to form the respective constructs; however the questions for trialability and observability were analyzed separately.

The appropriate model to use with count-type data is either a Poisson or a negative binomial regression model. In general, the negative binomial model is preferred as it does not restrict the mean and variance to be equal as does the Poisson model. The negative binomial model has the following form:

$$\lambda_i = EXP(\beta X_i + \varepsilon_i)$$

where λ_i is the expected number of events per period

β is a vector of parameters which will be estimated

X_i is a vector of explanatory variables, and

EXP (ε_i) is a gamma distributed error term with mean 1 and variance α^2 (Washington 2003).

The models illustrated in the following discussion all use one of the three dependent variables with the abbreviations of oosdrv, oosveh, or totaccs. The definitions of these dependent variables, as well as the control variables used in each model, are as follows:

- oosdrv - the number of driver inspections that resulted in a driver placed out-of-service in the 30-month period prior to the survey distribution,

- oosveh - the number of vehicle inspections that resulted in a vehicle placed out-of-service in the 30-month period prior to the survey distribution,
- totaccs - the number of total recordable accidents in the 30-month period prior to the survey distribution,
- drvinsp - the number of driver inspections in the 30-month period prior to the survey distribution,
- vehinsp - the number of vehicle inspections in the 30-month period prior to the survey distribution,
- powuntot - the number of power units,
- longbus - the length of time (years) the carrier has been in business,
- ltl - an indicator variable equal to one (1) if the carrier is primarily less-than-truckload, otherwise equal to zero (0), indicating truckload operation, and
- priv - an indicator variable equal to one (1) if the carrier is primarily private operation, otherwise equal to zero (0), indicating for-hire operation.

The descriptive statistics for the control variables are displayed in Table 7.

Table 7. Descriptive Statistics for Control Variables

Variable	N	Mean	Std Dev	Min	Max
oosdrv	97	36.38	127.04	0	1101
oosveh	97	95.19	313.27	0	2294
totaccs	97	51.90	211.17	0	1905
drvinsp	97	961.59	3184.36	3	23087
vehinsp	97	636.11	2032.63	3	15389
powuntot	97	528.48	1311.40	0	8642
longbus	87	32.27	24.59	3	100

For comparison purposes, three models were run with just the control variables and the dependent variables of total accidents driver out-of-service inspections, and vehicle out-of-service inspections. These results are displayed in Table 8, Table 9, and Table 10, respectively.

Table 8. All Control Variables with the Dependent Variable of Total Accidents

Parameter	Estimate	Standard Error	Chi-Square	Pr > ChiSq
Intercept	1.2510	0.4254	8.65	0.0033
powuntot	0.0017	0.0004	23.06	<.0001
ltl	-3.5582	1.4339	6.16	0.0131
priv	-1.6852	0.4095	16.93	<.0001
longbus	0.0222	0.0100	4.95	0.0260
Dispersion	2.6771	0.4978		
Log Likelihood = 25456.0110				

Table 9. All Control Variables with the Dependent Variable of Number of Driver Out-of-Service Inspections

Parameter	Estimate	Standard Error	Chi-Square	Pr > ChiSq
Intercept	1.4120	0.4731	8.91	0.0028
drvinsp	0.0009	0.0003	7.23	0.0072
powuntot	0.0011	0.0005	4.25	0.0392
drvinsp*powuntot	-0.0000	0.0000	16.33	<.0001
ltl	-3.6461	1.7420	4.38	0.0363
priv	-1.8188	0.4532	16.11	<.0001
longbus	0.0060	0.0104	0.33	0.5663
Dispersion	2.6514	0.5313		
Log Likelihood = 15801.7209				

Table 10. All Control Variables with the Dependent Variable of Number of Vehicle Out-of-Service Inspections

Parameter	Estimate	Standard Error	Chi-Square	Pr > ChiSq
Intercept	1.9898	0.3026	43.23	<.0001
vehinsp	0.0014	0.0003	17.10	<.0001
powuntot	0.0009	0.0003	6.79	0.0092
vehinsp*powuntot	0.0000	0.0000	30.97	<.0001
ltl	-2.3888	1.1501	4.31	0.0378
priv	-1.1424	0.2971	14.78	0.0001
longbus	0.0139	0.0068	4.21	0.0401
Dispersion	1.2747	0.2056		
Log Likelihood = 49137.5696				

Each of the control variables enter the models as would be expected, with the exception of the length of time the carrier has been in business. In each model, the number of accidents or out-of-service inspections increases with an increase in the number of inspections and the number of power units; companies that are less-than-truckload and/or private have fewer accidents or out-of-service inspections than companies that are truckload and/or for-hire. However, each model shows that the longer the company has been in business, the more crashes or out-of-service inspections they have.

In addition, a correlation analysis was run on all independent variables. The only variables with a correlation greater than 0.7 were the variables drvinsp and powuntot, and the variables vehinsp and powuntot. However, because of the importance of these variables in the model, they were both included in the respective models. Also, because it was anticipated that there would be an interaction effect between these variables, an interaction term was added to the models for these variables. Examining the results in Tables 8, 9, and 10 illustrate that this interaction term is significant.

The first hypothesis to be tested examined the relationship between technologies with higher ratings on the adoption factors and safety.

Hypothesis 1: For companies that have implemented a technology, those technologies that have one or more technology adoption factors with a high positive rating will have higher adoption rates, and more of a safety impact for the company, than technologies with no or fewer factors with high positive ratings.

Tables 11 through 17 illustrate the various adoption factor ratings for each technology. For example, Table 11 displays the relative advantage ratings for each technology. As presented, transponders for toll booths have the highest relative advantage ratings while collision avoidance systems have the lowest relative advantage ratings.

Table 11. Relative Advantage Ratings for Each Technology

Relative Advantage	N	Mean	Std Dev	Min	Max
1 - Transponders for Toll Booths	33	9.1212	1.6725	2	10
2 - Satellite for Communication	20	8.8000	1.9084	2	10
3 - Electronic Logbooks	5	8.6000	2.6077	4	10
4 - Cellular Phones	69	8.5797	1.9956	2	10
5 - Transponders for Weigh Stations	23	8.4783	2.2937	2	10
6 - Maintenance Tracking Software	23	8.2609	1.8394	2	10
7 - Computer-Aided Routing and/or Dispatching	36	8.0833	2.4885	2	10

Relative Advantage	N	Mean	Std Dev	Min	Max
8 - On-Board Computers for Vehicle Diagnostics	23	7.4348	2.3515	2	10
9 - On-Board Computers for Driver Performance	6	7.3333	3.2042	2	10
10 - Collision Avoidance Systems	6	5.8333	3.3116	2	10

Table 12 illustrates the compatibility ratings for each technology. Similar to the relative advantage ratings, transponders for toll booths have the highest compatibility ratings while collision avoidance systems have the lowest compatibility ratings.

Table 12. Compatibility Ratings for Each Technology

Compatibility	N	Mean	Std Dev	Min	Max
1 - Transponders for Toll Booths	33	9.1818	1.6289	2	10
2 - Satellite for Communication	20	8.5500	2.0641	2	10
3 - Cellular Phones	69	8.4203	2.0394	2	10
4 - Electronic Logbooks	5	8.4000	2.6077	4	10
5 - Transponders for Weigh Stations	23	8.3913	2.3304	2	10
6 - Computer-Aided Routing and/or Dispatching	35	8.1429	2.4869	2	10
7 - Maintenance Tracking Software	23	8.0870	2.0430	2	10
8 - On-Board Computers for Driver Performance	6	7.8333	2.9944	2	10
9 - On-Board Computers for Vehicle Diagnostics	23	7.6087	2.3498	2	10
10 - Collision Avoidance Systems	6	5.8333	3.4881	2	10

Table 13 illustrates the complexity ratings for each technology. The complexity-related questions for the survey were phrased in such a manner that higher ratings indicated less complexity. Similar to the relative advantage and compatibility ratings, transponders for toll booths have the highest positive complexity ratings while collision avoidance systems have the lowest positive complexity ratings.

Table 13. Complexity Ratings for Each Technology

Complexity	N	Mean	Std Dev	Min	Max
1 - Transponders for Toll Booths	32	9.0000	1.7598	2	10
2 - Cellular Phones	67	8.5075	1.9257	2	10
3 - Transponders for Weigh Stations	23	8.0870	2.2945	2	10
4 - Electronic Logbooks	5	7.8000	2.4900	4	10
5 - On-Board Computers for Driver Performance	6	7.6667	2.5820	3	10
6 - Satellite for Communication	20	7.5500	1.9861	4	10
7 - Computer-Aided Routing and/or Dispatching	36	7.2222	2.3557	2	10
8 - Maintenance Tracking Software	23	6.9130	1.8069	2	10
9 - On-Board Computers for Vehicle Diagnostics	23	6.5217	2.4096	2	10
10 - Collision Avoidance Systems	6	5.5000	3.3317	2	10

As described above, there are two separate questions for the construct of trialability that will be analyzed. The first, with the ratings for each technology illustrated in Table 14, asked the respondent if they agreed with the statement that they were able to try out [the technology] on a limited basis before they decided to fully implemented it. And, the second, with the ratings for each technology illustrated in Table 15, asked the respondent if they were able to implement [the technology] in phases rather than all at once.

Table 14. Trialability (Able to Try Out before Implementation) Ratings for Each Technology

Trialability - Able to Try Out before Implementation	N	Mean	Std Dev	Min	Max
1 - On-Board Computers for Driver Performance	6	4.0000	0.8944	3	5
2 - Satellite for Communication	20	3.6000	1.5009	1	5
3 - Collision Avoidance Systems	6	3.3333	1.6330	1	5
4 - Transponders for Weigh Stations	22	3.2727	1.5486	1	5
5 - Computer-Aided Routing and/or Dispatching	36	3.2500	1.5000	1	5
6 - On-Board Computers for Vehicle Diagnostics	23	3.0435	1.5515	1	5
7 - Cellular Phones	68	3.0147	1.5692	1	5
8 - Electronic Logbooks	5	2.8000	1.4832	1	5
9 - Maintenance Tracking Software	23	2.7826	1.3128	1	5
10 - Transponders for Toll Booths	31	2.5806	1.5869	1	5

Table 15. Trialability (Able to Implement in Phases) Ratings for Each Technology

Trialability - Able to Implent in Phases	N	Mean	Std Dev	Min	Max
1 - Transponders for Weigh Stations	23	4.0870	1.0835	1	5
2 - On-Board Computers for Driver Performance	6	4.0000	0.8944	3	5
3 - Satellite for Communication	20	3.7000	1.0809	2	5
4 - On-Board Computers for Vehicle Diagnostics	23	3.4783	1.3440	1	5
5 - Transponders for Toll Booths	31	3.3226	1.5997	1	5
6 - Maintenance Tracking Software	24	3.2500	1.5393	1	5
7 - Electronic Logbooks	5	3.2000	1.4832	1	5
8 - Computer-Aided Routing and/or Dispatching	36	3.1389	1.4958	1	5
9 - Collision Avoidance Systems	6	3.0000	1.8974	1	5
10 - Cellular Phones	67	2.6418	1.4740	1	5

As illustrated in Table 14, on-board computers for driver performance rated highest on this trialability construct, and this technology also rated second of all the technologies for the second trialability construct in Table 15. In addition, although transponders for toll booths rated highest in each of the three previous technology adoption factors, it rated lowest on one trialability factor, and fifth on the other.

Similar to the trialability factor, there are two separate questions for the construct of observability that are analyzed. The first, with the ratings for each technology illustrated in Table 16, asked the respondent if they agreed with the statement that they were able to observe other companies using [the technology] before they decided to try it. And, the second, with the ratings for each technology illustrated in Table 17, asked the respondent if once in use, their employees and/or customers could readily see and understand why they chose to implement [the technology].

Table 16. Observability (Observe Other Companies Before Trying) Ratings for Each Technology

Observability - Observe Other Companies Before Trying	N	Mean	Std Dev	Min	Max
1 - Satellite for Communication	20	3.3000	1.3416	1	5
2 - Maintenance Tracking Software	22	3.1364	1.1253	1	5
3 - On-Board Computers for Vehicle Diagnostics	23	3.0870	1.3455	1	5
4 - Computer-Aided Routing and/or Dispatching	36	2.9722	1.3833	1	5
5 - Transponders for Weigh Stations	23	2.9565	1.6090	1	5
6 - On-Board Computers for Driver Performance	6	2.8333	1.7224	1	5
7 - Transponders for Toll Booths	31	2.7419	1.6323	1	5
8 - Collision Avoidance Systems	6	2.5000	1.7607	1	5
9 - Cellular Phones	67	2.4328	1.4273	1	5
10 - Electronic Logbooks	5	2.0000	1.2247	1	4

Table 17. Observability (Employees and Customers Could See and Understand) Ratings for Each Technology

Observability - Employees and Customers Could See and Understand	N	Mean	Std Dev	Min	Max
1 - Satellite for Communication	20	4.2500	0.9105	1	5
2 - Transponders for Toll Booths	32	4.2500	1.1640	1	5
3 - Electronic Logbooks	5	4.2000	1.3038	2	5
4 - Cellular Phones	68	4.1029	1.1082	1	5
5 - Transponders for Weigh Stations	23	4.0870	1.1644	1	5
6 - On-Board Computers for Driver Performance	6	3.8333	1.6021	1	5
7 - Maintenance Tracking Software	24	3.8333	1.1293	1	5
8 - Computer-Aided Routing and/or Dispatching	36	3.7222	1.2561	1	5
9 - On-Board Computers for Vehicle Diagnostics	22	3.4545	1.2622	1	5
10 - Collision Avoidance Systems	6	2.5000	1.3784	1	5

As illustrated in Table 16, satellite for communication rated highest on this observability construct, and this technology also rated highest of all the technologies for the second observability construct in Table 17. In addition, although transponders for toll booths rated highest in each of the first three technology adoption factors, it rated seventh on one of the trialability factors.

Using a rating of 8.0 and above for the constructs that have a 1 to 10 scale and a rating of 4.0 and above for the constructs that have a 1 to 5 scale to define a “high positive rating,” the electronic clearance technologies had the most high positive ratings. The transponders for weigh stations technology has a high positive rating for almost all of the factors — relative advantage, compatibility, complexity, and one of the trialability and one of the observability constructs. The transponders for toll booths technology has a high positive rating for relative advantage, compatibility, complexity, and one of the observability constructs.

The freight mobility technologies also had technologies with high positive ratings, but not in quite as many factors across all the technologies. The cellular phone technology has a high positive rating for relative advantage, compatibility, complexity, and one of the observability constructs. The satellite for communication technology has high positive ratings for relative advantage, compatibility and one of the observability constructs. Both the computer-aided routing and/or dispatching technology and the maintenance tracking software technology have high positive ratings for relative advantage and compatibility.

Regarding the on-board safety monitoring technologies, the on-board computers for vehicle diagnostics technology did not rate high in any factor. Unfortunately, the use of on-board computers for driver performance, collision avoidance systems, and the use of electronic logbooks could not be tested due to the low number of companies who responded to the survey indicating use of these technologies, although in general these technologies did not rate high in many, if any, of the factors.

Given the above discussion, because both of the electronic clearance technologies and the freight mobility technology of cell phones had high positive ratings in almost every factor, it was anticipated that the use of these technologies may have the greatest impact on safety followed by the remainder of the freight mobility technologies.

Considering the transponder for toll booth technology, the first model examined used the dependent variable of total accidents. Other variables in the model included:

- transptoll - an indicator variable equal to one (1) if the carrier indicated using transponders for toll booth technology, otherwise equal to zero (0).
- powuntot - the number of power units the carrier has.
- transptolltime - the length of time that the carrier has been using transponders for toll booth technology. [Note that this variable is included in the model as transptoll*transptolltime so that this variable is equal to zero (0) for companies that do not use transponders for toll booth technology].
- ltl - an indicator variable equal to one (1) if the carrier is primarily less-than-truckload, otherwise equal to zero (0), indicating truckload operation.
- priv - an indicator variable equal to one (1) if the carrier is primarily private operation, otherwise equal to zero (0), indicating for-hire operation.
- longbus - the length of time (years) the carrier has been in business.

Analyzing the results of the negative binomial regression model presented in Table 18 reveals that the parameter estimate for the transponder for toll booth technology indicator variable is significant at the 0.05 level; however, the sign of the estimate is not as expected. The positive sign of the estimate indicates that the companies who use this technology are more likely to have more accidents than companies who do not use this technology. Other variables entered the model as would be expected — as the number of power units increase, the likelihood of crashes increase; companies with less than truckload and/or private operation are less likely to have crashes than companies with truckload and/or for-hire operation. As noted previously in the models with just the control variables, the longer a company has been in business, the more crashes they have. The length of time that the company was using the technology was not significant. Overall the model fits the data well with a log-likelihood equal to 25,459.3035. In addition, two other measures of goodness of fit, the values of Pearson Chi-Square and Deviance divided by the degrees of freedom, are close to one (1). These values are 0.8692 and 1.1037, respectively.

Table 18. Negative Binomial Regression Results for Toll Booth Technology with the Dependent Variable of Total Accidents

Parameter	Estimate	Standard Error	Chi-Square	Pr > ChiSq
Intercept	0.7443	0.4455	2.79	0.0948
transptoll	1.2144	0.6149	3.90	0.0483
powuntot	0.0014	0.0003	15.62	<.0001
transptoll*transptolltime	-0.0409	0.0914	0.20	0.6550
ltl	-3.5104	1.4018	6.27	0.0123
priv	-1.5819	0.4057	15.20	<.0001
longbus	0.0269	0.0105	6.51	0.0108
Dispersion	2.4182	0.4602		
Log-likelihood = 25459.3035				

Similar models were run using the dependent variables of the number of inspections that resulted in a driver placed out-of-service and the number of inspections that resulted in a vehicle placed out-of-service, respectively. Neither of these models revealed a significant parameter estimate for the transponder for toll booth technology indicator variable, and similar to the model presented above, all other variables entered the models as would be expected.

The second set of models examined the transponder for weigh stations technology and used the new variables:

- transpwt - an indicator variable equal to one (1) if the carrier indicated using transponders for weigh station technology, otherwise equal to zero (0).
- transpwttime - the length of time that the carrier has been using transponders for weigh station technology. [Note that this variable is included in the model as transpwt*transpwttime so that this variable is equal to zero (0) for companies that do not use transponders for weigh stations technology].

Similar to the results in Table 18, analyzing the results of the negative binomial regression model presented in Table 19 reveals that the parameter estimate for the transponder for weigh stations technology indicator variable is significant at the 0.0001 level; however, once again the sign of the estimate is not as expected. The positive sign of the estimate indicates that the companies who use this technology are more likely to have more accidents than companies who do not use this technology. As above, the other variables entered the model as would be expected. The model fits the data well with a log-likelihood equal to 25,465.0636. In addition, two other measures of goodness of fit, the values of Pearson Chi-Square and Deviance divided by the degrees of freedom, are close to one (1). These values are 1.2704 and 1.1267, respectively.

Table 19. Negative Binomial Regression Results for the Transponders for Weigh Station Technology with the Dependent Variable of Total Accidents

Parameter	Estimate	Standard Error	Chi-Square	Pr > ChiSq
Intercept	0.1242	0.4179	0.09	0.7663
transpwt	2.4525	0.5984	16.80	<.0001
powuntot	0.0011	0.0003	19.16	<.0001
transpwt*transpwttime	-0.1229	0.0764	2.59	0.1075
ltl	-3.5056	1.1944	8.61	0.0033
priv	-0.6950	0.3941	3.11	0.0778
longbus	0.0321	0.0089	13.14	0.0003
Dispersion	1.9480	0.3947		
Log Likelihood = 25465.0636				

Similar models were run using the dependent variables of the number of inspections that resulted in a driver placed out-of-service and the number of inspections that resulted in a vehicle placed out-of-service, respectively. Neither of these models revealed a significant parameter estimate for the transponder for weigh station technology indicator variable, and similar to the model presented above, all other variables entered the models as would be expected.

Examining the freight mobility technologies, an analysis of the negative binomial regression models for both the cellular phone and the satellite technologies with all three dependent variables revealed that none of the models had significant parameter estimates for either of these technology indicator variables.

The model including the indicator variable for maintenance tracking software with the dependent variable of total accidents revealed the results presented in Table 20. The new variables in this model are:

- maint - an indicator variable equal to one (1) if the carrier indicated using maintenance tracking software technology, otherwise equal to zero (0).
- mainttime - the length of time that the carrier has been using maintenance tracking software. [Note that this variable is included in the model as maint*mainttime so that this variable is equal to zero (0) for companies that do not use maintenance tracking software technology].

Analyzing the results of the negative binomial regression model presented in Table 20 reveals that the parameter estimate for the maintenance tracking software technology indicator variable is significant at the 0.02 level; however, once again the sign of the estimate is not as expected. The positive sign of the estimate indicates that the companies who use this technology are more likely to have more accidents than companies who do not use this technology. As above, the other variables entered the model as would be expected. The model fits the data well with a log-likelihood equal to 25,460.1104. In addition, two other measures of goodness of fit, the values of Pearson Chi-Square and Deviance divided by the degrees of freedom, are close to one (1). These values are 0.9530 and 1.1160, respectively.

Table 20. Negative Binomial Regression Results for the Maintenance Tracking Software Technology with the Dependent Variable of Total Accidents

Parameter	**Estimate**	**Standard Error**	**Chi-Square**	**Pr > ChiSq**
Intercept	1.1030	0.3897	8.01	0.0046
maint	1.2574	0.4984	6.36	0.0116
powuntot	0.0014	0.0003	21.04	<.0001
maint*mainttime	-0.0189	0.0418	0.20	0.6519
ltl	-2.9042	1.3926	4.35	0.0370

Parameter	Estimate	Standard Error	Chi-Square	Pr > ChiSq
priv	-1.5473	0.3817	16.44	<.0001
longbus	0.0152	0.0093	2.65	0.1034
Dispersion	2.3205	0.4492		
Log Likelihood = 25460.1104				

The final freight mobility technology models included an indicator variable for computer-aided routing and/or dispatching technology, and the results of the first model — with the dependent variable of the number of driver inspections that resulted in a driver placed out-of-service — are displayed in Table 21. This model includes the new and additional variables of:

- compaid - an indicator variable equal to one (1) if the carrier indicated using computer-aided routing and/or dispatching technology, otherwise equal to zero (0).
- compaidtime - the length of time that the carrier has been using computer-aided routing and/or dispatching. [Note that this variable is included in the model as compaid*compaidtime so that this variable is equal to zero (0) for companies that do not use computer-aided routing and/or dispatching technology].
- drvinsp - the number of driver inspections the carrier has had in the 30 months prior to August 2005. [Note that because of the interaction between the number of power units and the number of driver inspections, an interaction term of these two variables has been added to the model].

Analyzing the results of the negative binomial regression model presented in Table 21 reveals that the parameter estimate for the computer-aided routing and/or dispatching technology indicator variable is significant at the 0.02 level; however, once again the sign of the estimate is not as expected. The positive sign of the estimate indicates that the companies who use this technology are more likely to have more driver out-of-service inspections than companies who do not use this technology. As above, most of the other variables entered the model as would be expected, including the new variable indicating that as the number of driver inspections increases so does the likelihood of driver out-of-service inspections. The interaction term of the number of power units with the number of driver inspections is significant as expected. The model fits the data well with a log-likelihood equal to 15,807.7749. In addition, two other measures of goodness of fit, the values of Pearson Chi-Square and Deviance divided by the degrees of freedom, are close to one (1). These values are 1.0612 and 1.0730, respectively.

Table 21. Negative Binomial Regression Results for the Computer-Aided Routing and/or Dispatching Technology with the Dependent Variable of Number of Driver Out-of-Service Inspections

Parameter	Estimate	Standard Error	Chi-Square	Pr > ChiSq
Intercept	0.1444	0.5416	0.07	0.7898
compaid	1.1718	0.4700	6.21	0.0127
drvinsp	0.0010	0.0003	11.30	0.0008
powuntot	0.0008	0.0005	2.73	0.0985
drvinsp*powuntot	-0.0000	0.0000	22.81	<.0001
compaid*compaidtime	0.0284	0.0415	0.47	0.4947
ltl	-2.8535	1.5885	3.23	0.0724
priv	-1.4386	0.4388	10.75	0.0010

Parameter	Estimate	Standard Error	Chi-Square	Pr > ChiSq
longbus	0.0187	0.0107	3.04	0.0811
Dispersion	2.2064	0.4536		
Log Likelihood = 15807.7749				

A second similar model run with the dependent variable of the number of vehicle inspections that resulted in a vehicle placed out-of-service yielded very similar results. The parameter estimate for the computer-aided routing and/or dispatching technology indicator variable was significant at the 0.05 level, with a positive sign of the estimate indicating that the companies who use this technology are more likely to have more vehicle out-of-service inspections than companies who do not use this technology.

The third model run with the dependent variable of total accidents did not yield a significant parameter estimate for the computer-aided routing and/or dispatching technology indicator variable.

Examining the final set of technologies, those associated with on-board safety monitoring, revealed no significant parameter estimates for any model for the on-board computers for vehicle diagnostics indicator variable. The other technologies in this area had too few respondents to the survey for analysis.

5.2.1 Discussion of Hypothesis 1 Testing Results

The results regarding the hypothesis 1 testing are mixed. Because of the high ratings of the freight mobility technologies in many adoption factors, the anticipation was that the use of these technologies would have a greater effect on safety than other technologies, such as the on-board safety monitoring technologies that did not rate high on average in any adoption factor. While it is true that the models illustrated that the on-board safety monitoring technology of on-board computers for vehicle diagnostics had no significant effect on safety, in terms of either out-of-service inspections or crashes; unfortunately, the models illustrated that technologies in both the freight mobility area and the electronic clearance area had a negative effect on safety. Across all these technologies in both areas, those with significant parameter estimates indicated that the use of these technologies had a negative safety impact.

As discussed in an earlier chapter, these results are not all together surprising as research has shown that use of certain technologies can have a distraction effect and a negative impact on safety. In addition, there is a potential for less safety inspections for those companies that bypass weigh stations on a regular basis.

5.3 Hypotheses Specific to the Commercial Vehicle Industry Results

This set of hypotheses examines each technology individually and utilizes negative binomial regression models to determine if the ratings for each adoption factor for each technology have an impact on one or more of the dependent safety variables examined. In order to rate the technology adoption factors, the company must be using the technology. As discussed, the theory is that the higher the technology adoption factor ratings for the technology, the more of a safety impact the technology will have.

Hypothesis 2: The implementation of technologies related to electronic clearance, on-board safety monitoring, and freight mobility will impact the safety of the company (in terms of accidents and safety violations).

This hypothesis basically states that the implementation of a technology will have an effect on safety, regardless of the associated adoption factors. The models used to test this hypothesis are the same as those used for Hypothesis 1, and as was discussed above, those companies that implemented a technology either had no significant difference in safety or they had a worse safety record compared to those companies that did not implement the technology.

Hypothesis 2a: The successful adoption of technologies related to electronic clearance, on-board safety monitoring, and freight mobility will impact the safety of the company (in terms of accidents and safety violations).

As opposed to Hypothesis 2, this hypothesis states that the <u>successful adoption and use</u> of a technology will have an effect on safety.

An initial correlation analysis revealed that several of the adoption factor constructs were highly correlated with one another. Thus, a principal components analysis was performed on each set of constructs measured for each technology. This type of analysis is appropriate for data reduction purposes where fewer measures can be used to still adequately capture the data (Johnson and Wichern1988). From this analysis, the constructs were combined to form two or three principal components that still were sufficient to adequately summarize the data. Rather than simply summing the constructs together, one construct was selected from each principal component to be used in each analysis.

For example, for the freight mobility technology of cellular phones, the two principal components, or clusters, formed from the analysis consisted of (1) a combination of the relative advantage construct, the compatibility construct, the complexity construct, and one observability construct (employees and customers could see and understand); and (2) a combination of both trialability constructs and one observability construct (observe other companies before trying). The constructs selected for use in the final models were one of the relative advantage constructs and one of the trialbility constructs.

The principal components analysis revealed the same combinations as above for the technologies of on-board computers for vehicle diagnostics, on-board computers for driver performance, transponders for toll booths, transponders for weigh stations, computer-aided routing and/or dispatching, and maintenance tracking software.

The principal components analysis for the satellite for communication technology revealed the same first combination of the relative advantage construct, the compatibility construct, the complexity construct, and one observability construct (employees and customers could see and understand); but there were two more clusters identified — one with one of the trialability constructs (able to try out) and one of the observability constructs (able to observe other companies); and one with the remaining trialability construct (able to implement in phases). Thus, the constructs selected for use in the final models for this technology were one of the relative advantage constructs, and both of the trialability constructs.

Similarly, the principal components analysis for the electronic logbooks technology revealed three clusters - one with a combination of the relative advantage construct, the compatibility constructs, one complexity construct (easy to become skillful), one observability construct (employees and/or customers could readily see and understand), and one trialability construct (able to implement in phases); one with one of the complexity constructs (learning to interact was easy) and one of the trialability constructs (able to try out); and one with the remaining observability construct (able to observe other companies). Thus, the constructs selected for use in the final models for this technology were one of the relative advantage constructs, one of the trialability constructs, and one of the observability constructs.

Finally, the principal components analysis for the collision avoidance systems technology revealed that all the adoption factors could be combined into one cluster.

Beginning with the freight mobility technologies, the first models examined cellular phone technology. The results displayed in Table 22 are for the model with the dependent variable of total accidents, and the new / additional variables included:

- cellclus1 - an adoption factor rating that through cluster analysis represents the relative advantage construct, the compatibility construct, the complexity construct, and one observability construct (employees and customers could see and understand) for rating cellular phone technology. It can range from 1 to 5.

- cellclus2 - an adoption factor rating that through cluster analysis represents both trialability constructs and one observability construct (observe other companies before trying) for rating cellular phone technology. It can range from 1 to 5.
- celltime - the length of time that the carrier has been using cellular phone technology.

Note that for these models, only observations are included for companies that indicated implementation of cellular phone technology, and thus were able to answer the technology adoption factor questions. With missing values for some responses, the sample for this model in Table 22 is n=62.

Analyzing the results of the negative binomial regression model presented in Table 22 reveals that the parameter estimate for the cellclus1 adoption factor rating is moderately significant at the 0.07 level; and, the sign of the estimate is as would be expected. The negative sign of the estimate indicates that the companies that have implemented cellular phone technology and rated the adoption factors included in this cluster higher are likely to have fewer accidents than companies who implemented cellular phone technology and rated the adoption factors included in this cluster lower. Other variables entered the model as would be expected — as the number of power units increase, the likelihood of crashes increase; companies with less than truckload and/or private operation are less likely to have crashes than companies with truckload and/or for-hire operation; and as noted previously, the longer a company has been in business, the more likelihood of crashes. The length of time that the company was using the technology was not significant. Overall the model fits the data well with a log-likelihood equal to 2,093.5345. In addition, two other measures of goodness of fit, the values of Pearson Chi-Square and Deviance divided by the degrees of freedom, are close to one (1). These values are 1.1627 and 1.0249, respectively.

Table 22. Negative Binomial Regression Results for the Adoption Factors Related to Cellular Phone Technology with the Dependent Variable of Total Accidents

Parameter	Estimate	Standard Error	Chi-Square	Pr > ChiSq
Intercept	0.6918	1.3184	0.28	0.5998
cellclus1	-0.4292	0.2346	3.35	0.0674
cellclus2	0.2572	0.1760	2.14	0.1439
powuntot	0.0040	0.0010	16.44	<.0001
celltime	-0.0481	0.0489	0.97	0.3255
ltl	-9.4893	2.9719	10.20	0.0014
priv	-0.9812	0.5478	3.21	0.0733
longbus	0.0447	0.0133	11.34	0.0008
Dispersion	1.8283	0.5261		
Log Likelihood = 2093.5345				

Examining the results of similar models using the number of driver out-of-service inspections and the number of vehicle out-of-service inspections as the dependent variable revealed that the adoption factor cluster variables for cellular phone technology were not significant in these models.

Considering the other freight mobility technologies of satellite communication, computer-aided routing and/or dispatching technology, and maintenance tracking software revealed that none of the binomial regression models with any of the three dependent variables resulted in significant parameter estimates for the adoption factor cluster variables.

Examining the electronic clearance technologies, the results displayed in Table 23 consider the transponder for toll booth technology and are for the model with the dependent variable of the number of driver out-of-service inspections. The new variables for this model included:

- transptollclus1 - an adoption factor rating that through cluster analysis represents the relative advantage construct, the compatibility construct, the complexity construct, and one observability construct (employees and customers could see and understand) for rating transponder for toll booth technology. It can range from 1 to 5.
- transptollclus2 - an adoption factor rating that through cluster analysis represents both trialability constructs and one observability construct (observe other companies before trying) for rating transponder for toll booth technology. It can range from 1 to 5.
- transptolltime - the length of time that the carrier has been using transponder for toll booth technology.

Note once again that for these models, only observations are included for companies that indicated implementation of transponder for toll booth technology, and thus were able to answer the technology adoption factor questions. With missing values for some responses, the sample for this model in Table 23 is n=30.

Analyzing the results of the negative binomial regression model presented in Table 23 reveals that the parameter estimate for the tranptollclus1 adoption factor rating is not significant and the parameter estimate for the tranptollclus2 adoption factor rating is moderately significant at the 0.06 level. However, the sign of the estimate is not as would be expected. The positive sign of the estimate indicates that the companies who have implemented transponder for toll booth technology and rated the adoption factors included in this cluster lower are likely to have fewer driver out-of-service inspections than companies who implemented transponder for toll booth technology and rated the adoption factors included in this cluster higher. As before, the other variables entered the model as would be expected. Overall the model fits the data well with a log-likelihood equal to 13,179.2582. In addition, two other measures of goodness of fit, the values of Pearson Chi-Square and Deviance divided by the degrees of freedom, are close to one (1). These values are 1.3489 and 1.7102, respectively.

Table 23. Negative Binomial Regression Results for the Adoption Factors Related to Transponder for Toll Booth Technology with the Dependent Variable of Number of Driver Out-of-Service Inspections

Parameter	Estimate	Standard Error	Chi-Square	Pr > ChiSq
Intercept	1.8914	1.2195	2.41	0.1209
transptollclus1	-0.0728	0.2320	0.10	0.7537
transptollclus2	0.2631	0.1361	3.74	0.0533
drvinsp	0.0003	0.0001	6.00	0.0143
powuntot	0.0010	0.0003	9.53	0.002
drvinsp*powuntot	0.0000	0.0000	10.47	0.0012
transptolltime	-0.0475	0.0856	0.31	0.5788
ltl	-2.5253	1.1613	4.73	0.0297
priv	-2.3467	0.5245	20.02	<.0001
longbus	0.0085	0.0104	0.67	0.4118
Dispersion	0.6768	0.2272		
Log Likelihood = 13179.2582				

Examining the results of similar models using the number of vehicle out-of-service inspections and total crashes as the dependent variable revealed that the adoption factor cluster variables for transponder for toll booth technology were not significant in these models.

In addition, analyzing the models for the other electronic clearance technology of transponders for weigh stations revealed that none of the binomial regression models with any of the three dependent variables resulted in significant parameter estimates for the adoption factor cluster variables.

Finally, examining the on-board safety monitoring technology of on-board computers for vehicle diagnostics, the results displayed in Table 24 are for the model with the dependent variable of the number of total accidents. The new variables for this model included:

- compvehclus1 - an adoption factor rating that through cluster analysis represents the relative advantage construct, the compatibility construct, the complexity construct, and one observability construct (employees and customers could see and understand) for rating on-board computers for vehicle diagnostics technology. It can range from 1 to 5.
- compvehclus2 - an adoption factor rating that through cluster analysis represents both trialability constructs and one observability construct (observe other companies before trying) for rating on-board computers for vehicle diagnostics technology. It can range from 1 to 5.

- compvehtime - the length of time that the carrier has been using on-board computers for vehicle diagnostics technology.

Note once again that for these models, observations are included only for companies that indicated implementation of on-board computers for vehicle diagnostics technology, and thus were able to answer the technology adoption factor questions. With missing values for some responses, the sample for this model in Table 24 is n=22.

Analyzing the results of the negative binomial regression model presented in Table 24 reveals that the parameter estimate for the compvehclus1 adoption factor rating is significant at the 0.05 level and the parameter estimate for the compvehclus2 adoption factor rating is moderately significant at the 0.07 level. The sign of the parameter estimate for the compvehclus1 adoption factor rating is as would be expected. The negative sign of this estimate indicates that the companies who have implemented on-board computers for vehicle diagnostics technology and rated the adoption factors included in this cluster higher are likely to have fewer accidents than companies that implemented on-board computers for vehicle diagnostics technology and rated the adoption factors included in this cluster lower. However, the positive sign of the parameter estimate for the compvehclus2 adoption factor rating indicates that the companies who have implemented on-board computers for vehicle diagnostics technology and rated the adoption factors included in this cluster lower are likely to have fewer accidents than companies who implemented on-board computers for vehicle diagnostics technology and rated the adoption factors included in this cluster higher. As before, the other significant variables entered the model as would be expected. Overall the model fits the data well with a log-likelihood equal to 19,655.2625. In addition, two other measures of goodness of fit, the values of Pearson Chi-Square and Deviance divided by the degrees of freedom, are close to one (1). These values are 1.0169 and 1.8025, respectively.

Table 24. Negative Binomial Regression Results for the Adoption Factors Related to On-Board Computers for Vehicle Diagnostics Technology with the Dependent Variable of Number of Total Accidents

Parameter	Estimate	Standard Error	Chi-Square	Pr > ChiSq
Intercept	4.4777	0.9010	24.70	<0.0001
compvehclus1	-0.5649	0.2848	3.93	0.0473
compvehclus2	0.4906	0.2694	3.32	0.0686
powuntot	0.0009	0.0002	24.03	<.0001
compvehtime	-0.0826	0.0540	2.34	0.1260
ltl	-0.1237	1.3541	0.01	0.9272
priv	-1.0310	0.9140	1.27	0.2593
longbus	-0.0224	0.0154	2.12	0.1459
Dispersion	1.2121	0.4128		
Log Likelihood = 19655.2625				

Examining the results of similar models using the number of driver out-of-service inspections and the number of vehicle out-of-service inspections as the dependent variable revealed that the adoption factor cluster variables for on-board computers for vehicle diagnostics technology were not significant in these models.

As noted previously, the other on-board safety monitoring technologies had too few respondents in the survey to be analyzed.

5.3.1 Discussion of Hypothesis 2a Testing Results

Similar to the discussion regarding Hypothesis 1 and Hypothesis 2, the results of Hypothesis 2a are mixed. It was anticipated that the successful adoption of a technology (i.e., higher ratings on the adoption factors) would result in an affect on safety. This was the case when considering one adoption factor cluster with both cellular phone technology and on-board computers for vehicle diagnostics technology. As opposed to the results when considering simply the implementation of the technology, the results for these two technologies revealed that the companies who have implemented these technologies and rated one cluster of adoption factors higher are likely to have fewer accidents than companies that implemented these technologies and rated the one cluster of adoption factors lower. The moderately significant results for one additional technology, the transponder for toll booth technology, indicated that companies who implement this technology and rate the adoption factors higher have an increase in the number of inspections resulting in a driver placed out-of-service (the results with regards to accidents, however, were not significant).

With regard to cell phone technology, these results are very interesting. Simply implementing cell phone technology resulted in a negative impact on safety. However, when considering all companies that implemented cell phone technology, those that more successfully adopted the technology had fewer accidents than those with lower ratings on the adoption factors. It could be that the companies who rated the adoption factors higher also have a strict policy in place for the use of the cell phones, and thus realize more of the safety benefits than companies that do not have such a policy. In addition, these companies could also have more safety-related policies in general thus making them safer than companies without these policies.

Considering on-board computers for vehicle diagnostics, there was no safety effect noted with simply implementing the technology. However, of the companies implementing the technology, those that rated one cluster of adoption factors higher did have fewer accidents. This clearly illustrates what was trying to be captured with the adoption factors. If a company implements on-board computers for vehicle diagnostics technology, but does not take the time to actually learn and use the information from it, it makes sense that there would be no impact on safety. Conversely, when comparing companies with higher ratings on the adoption factors, there is a positive safety effect (e.g., those companies that successfully adopted this technology are safer than those who did not successfully adopt).

No other technologies yielded significant results for this hypothesis which leads to the conclusion that a company's successful adoption of these technologies does not lead to more safety than companies that do not successfully adopt these technologies.

CHAPTER 6. SUMMARY AND CONCLUSIONS

Because of the importance of safety, and the potential benefits for both the general public and the commercial vehicle industry of improving safety, the main goal of this project was to identify those commercial vehicle-related technologies that, through successful adoption, have had a positive impact on the safety of motor carrier companies. This was examined through two perspectives, one simply examining the effect of a technology implementation on safety, and the second identifying the effect of a successful adoption of a technology (as compared to a less successful adoption of a technology) on safety. It is anticipated that the information discovered in this project can be used by commercial vehicle companies to aid them in implementing technologies that will be of the greatest benefit to both them and their customers. In addition, the information can be used by government agencies to help them to target their efforts towards advocating the implementation of technologies that have the greatest potential safety impact.

Given the importance of safety and controlling for other factors as much as possible, this study identified which technologies motor carriers have implemented that have had an impact on safety. Technology adoption theory was used to explore specific aspects of the technologies that led to their successful or unsuccessful adoption. It was hypothesized that technologies with factors that lead to successful adoption will have a greater safety impact.

There already exists a nationwide database of interstate motor carriers maintained by the U.S. Department of Transportation which contains safety-related information. Therefore, the only additional information needed to conduct the analysis was which technologies motor carriers have in place and the innovation adoption factors associated with the technology. Unfortunately, no database currently exists that has this information. Thus, a survey of a stratified random sample or carriers was used to obtain the necessary data. Information regarding technology use was collected in three areas of technologies — freight mobility, on-board safety monitoring, and electronic clearance. Each of these has the potential for a positive or negative safety impact depending on their implementation and use.

Negative binomial regression models with the dependent variables of three separate measures of safety (number of accidents, number of driver out-of-service inspections, and number of vehicle out of service inspections) were utilized to test each technology. The effect on safety with the simple implementation of each technology as well as the effect on safety with the successful adoption of each technology was examined.

The overall results were mixed. Considering the simple implementation of the technology, because of the high ratings of the freight mobility technologies in many adoption factors, the anticipation was that the use of these technologies would have a greater effect on safety than other technologies, such as the on-board safety monitoring technologies that did not rate high on average in any adoption factor. While it is true that the models illustrated that the on-board safety monitoring technology of on-board computers for vehicle diagnostics had no significant effect on safety, in terms of either out-of-service inspections or crashes; unfortunately, the models illustrated that technologies in both the freight mobility area and the electronic clearance area had a negative effect on safety. Across all these technologies in both areas, those with significant parameter estimates indicated that the use of these technologies had a negative safety impact.

Examining the successful adoption of technology (as compared to those companies with less successful adoption), the results were also mixed. It was anticipated that the successful adoption of a technology (i.e., higher ratings on the adoption factors) would result in an effect on safety. This was the case when considering one adoption factor cluster with both cellular phone technology and on-board computers for vehicle diagnostics technology. As opposed to the results when considering simply the implementation of the technology, the results for these two technologies revealed that the companies who have implemented these technologies and rated one cluster of adoption factors higher are likely to have fewer accidents than companies who implemented these technologies and rated the one cluster of adoption factors lower. The moderately significant results for one additional technology, the transponder for toll booth technology, indicated that companies who implement this technology and rate the adoption factors higher have an increase in the number of inspections resulting in a driver placed out-of-service (the results with regards to accidents, however, were not significant).

With regard to cell phone technology, these results were very interesting. Simply implementing cell phone technology resulted in a negative impact on safety. However, when considering all companies that implemented cell phone technology, those that more successfully adopted the technology had fewer accidents than those with lower ratings on the adoption factors.

Considering on-board computers for vehicle diagnostics, there was no safety effect noted with simply implementing the technology; however, of the companies implementing the technology, those that rated one cluster of adoption factors higher did have fewer accidents. Logically, if a company implements on-board computers for vehicle diagnostics technology, but does not take the time to actually learn and use the information from it, it makes sense that there would be no impact on safety. Conversely, when comparing companies with higher ratings on the adoption factors, there is a positive safety effect (e.g., those companies that successfully adopted this technology are safer than those who did not successfully adopt). No other technologies yielded significant results.

6.1 Implications for Companies and Government

The main implication of this study for both commercial vehicle companies and government agencies is that simply implementing a technology, or advocating implementing a technology, may not give a desired result, and in some cases may even result in a negative impact on safety. Specifically, the study results revealed that companies that had implemented technologies in either the freight mobility or the electronic clearance areas had worse safety records than companies who had not implemented these technologies.

However, for at least two of the technologies, out of all companies that had implemented the technologies, those companies that successfully adopted the technologies had better safety records than those companies that did not successfully adopt the technologies. The implication is that the company needs to take the time to learn the technology and integrate it fully into the company in the right way in order for it to have a positive impact. Similarly, government agencies should examine companies that have successfully implemented certain technologies and that have a good safety record to determine the steps they took during the implementation. Providing this information to other companies examining implementing a technology could prove very useful and assist them toward a positive safety impact from the technology.

6.2 Further Research

This is the first study of its kind to attempt to link technology use to safety in the commercial vehicle industry. Safety is impacted by a wide variety of factors, and although there was some evidence of a link with successful adoption of certain technologies and safety, further research should attempt to obtain larger sample sizes of companies using particular technologies in order to test all technologies as well as interaction effects with the use of more than one technology. Additional data should also be obtained regarding other variables that may have a potential effect on the safety of a company, such as turnover rates, profitability, or general company policies that could have a moderating effect on other variables used in the analysis. In addition, a better understanding of company policies could help to explain some of the results observed.

For the model development, it may be useful for future research to examine the use of vehicle miles traveled instead of power units as the exposure variable and perhaps also create categories for the continuous variables, such as company size.

Although discussed briefly, future research could also explore more the use inventory-theoretic models for demonstrating the benefits of technology implementation.

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Appendix A: Technology Survey

Subject: Commercial Vehicle Company Technology Survey

Dear IT Director:

We are requesting your assistance with an important research project that we anticipate will improve commercial vehicle safety. This is a joint project between North Dakota State University's Upper Great Plains Transportation Institute and the Pennsylvania State University. Commercial vehicle companies of various sizes nationwide were randomly selected for participation in this study.

If you prefer, this survey can also be easily completed via the Internet by accessing the site: http://www.ugpti.org/tech/. Please have your company's US DOT number available.

Before completing the enclosed survey, please read the implied informed consent form on the following page.

Once you have completed the survey, please return it using the enclosed postage-paid business reply envelope.

All individual responses to this survey will remain confidential and the results will be released only in an aggregate form. It is anticipated that the results from this study will be available December 2005 from the web site: http://www.ugpti.org/.

If you have any questions regarding this study, please feel free to contact Brenda Lantz (720-238-0070, brenda.lantz@ndsu.edu) or Dr. Pete Swan (717-948-6443, pfs4@psu.edu).

Thank you in advance for your assistance.

Sincerely,

Brenda Lantz
Program Director

Implied Informed Consent Form
for Social Science Research
The Pennsylvania State University

ORP USE ONLY: IRB# 21485

The Pennsylvania State University

Office for Research Protections

Title of Project: *The Effects of Technologies on Commercial Vehicle Company Safety and Service*

Principal Investigator: Brenda Lantz, Graduate Student
TELEPHONE: 720-238-0070
EMAIL: bml131@psu.edu

Advisor: Pete Swan,
The Business School
Harrisburg Capital College
TELEPHONE: 717-948-6443
EMAIL: pfs4@psu.edu

1. **Purpose of the Study:** The purpose of this research is to answer the questions regarding which technologies have had the greatest impact on safety and service in the commercial vehicle industry and why, and what factors regarding the company or the technology lead to this impact. It is anticipated that the results of this study will lead to improved commercial vehicle safety.
2. **Procedures to be followed:** You will be asked to answer questions in a survey, and then mail back the survey in the provided postage-paid envelope or submit your responses via the web site.
3. **Discomforts and Risks:** There are no risks to participants beyond what would be encountered in normal daily living.
4. **Benefits:** The benefits to you include learning information regarding the types of technologies that have the greatest positive safety impact. The benefits to society include potential improved commercial vehicle safety.
5. **Duration/Time:** This questionnaire should take approximately 15 minutes to complete.
6. **Statement of Confidentiality:** The surveys will be coded for each individual company so that we have a record of which companies have completed the questionnaire (so that they are not included in reminders to return the survey). No specific individual information will be collected that would link individual responses to a personally identifiable indicator such as name or title of the company. All individual responses to this survey will remain confidential and the results of this study will be released only in an aggregate form. The Office for Research Protections may review records related to this research.
7. **Right to Ask Questions:** You can ask questions about this research. Contact Brenda Lantz (720-238-0070, bml131@psu.edu) or Dr. Pete Swan (717-948-6443, pfs4@psu.edu) with questions. If you have questions about your rights as a research participant, contact The Pennsylvania State University's Office for Research Protections at (814) 865-1775.

8. **Compensation:** There is no compensation available for your participation in the research.
9. **Voluntary Participation:** Your decision to be in this research is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer.

You must be 18 years of age or older to take part in this research study.

Completion and return of the survey implies that you have read the information in this form and consent to take part in the research.

If completing this survey via the Internet, your confidentiality will be kept to the degree permitted by the technology used. No guarantees can be made regarding the interception of data sent via the Internet by any third parties.

Please keep this form for your records or future reference.

Commercial Vehicle Company Technology Survey

August 2005

PENNSTATE

1855

UGPTI

We are requesting your assistance with an important research project that we anticipate will improve commercial vehicle safety. Commercial vehicle companies of various sizes nationwide were randomly selected for participation in this study. This is a joint project between North Dakota State University's Upper Great Plains Transportation Institute and the Pennsylvania State University, and is being conducted as partial requirements for completion of a dissertation at the Pennsylvania State University.

If you have any questions regarding this study, please contact Brenda Lantz (720-238-0070, brenda.lantz@ndsu.edu) or Dr. Pete Swan (717-948-6443, pfs4@psu.edu).

All individual responses to this survey will remain confidential and the results of this study will be released only in an aggregate form. It is anticipated that the results from this study will be available December 2005 from the web site at www.ugpti.org.

TECHNOLOGY USE

1. **Does your company (Do you) currently use cellular phones for communications between dispatcher and driver(s)?**

    No (please continue to Question 1a)
    Yes (please answer the questions on pages 7-8)

    1a. Did your company (Did you) ever use this technology in the past?

    No (please continue to Question 2)
    Yes (please indicate the year(s) the technology was in use and why it was discontinued, then continue to Question 2).

    ____

    ____

2. **Does your company (Do you) currently use satellite for communications between the dispatcher and driver(s)?**

    No (please continue to Question 2a)
    Yes (please answer the questions on pages 9-10)

    2a. Did your company (Did you) ever use this technology in the past?

    No (please continue to Question 3)
    Yes (please indicate the year(s) the technology was in use and why it was discontinued, then continue to Question 3).

    ____

    ____

3. Does your company (Do you) currently use on-board or handheld computers for vehicle diagnostics?

No (please continue to Question 3a)
Yes (please answer the questions on pages 11-12)

3a. Did your company (Did you) ever use this technology in the past?

No (please continue to Question 4)
Yes (please indicate the year(s) the technology was in use and why it was discontinued, then continue to Question 4).

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4. Does your company (Do you) currently use on-board or handheld computers for driver performance?

No (please continue to Question 4a)
Yes (please answer the questions on pages 13-14)

4a. Did your company (Did you) ever use this technology in the past?

No (please continue to Question 5)
Yes (please indicate the year(s) the technology was in use and why it was discontinued, then continue to Question 5).

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5. **Does your company (Do you) currently use electronic logbooks for monitoring driver hours of service?**

No (please continue to Question 5a)
Yes (please answer the questions on pages 15-16)

5a. **Did your company (Did you) ever use this technology in the past?**

No (please continue to Question 6)
Yes (please indicate the year(s) the technology was in use and why it was discontinued, then continue to Question 6).

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6. **Does your company (Do you) currently use transponders for toll booths?**

No (please continue to Question 6a)
Yes (please answer the questions on pages 17-18)

6a. **Did your company (Did you) ever use this technology in the past?**

No (please continue to Question 7)
Yes (please indicate the year(s) the technology was in use and why it was discontinued, then continue to Question 7).

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7. Does your company (Do you) currently use transponders for weigh stations (PrePass, NorPASS, etc.)?

No (please continue to Question 7a)
Yes (please answer the questions on pages 19-20)

7a. Did your company (Did you) ever use this technology in the past?

No (please continue to Question 8)
Yes (please indicate the year(s) the technology was in use and why it was discontinued, then continue to Question 8).

____

____

8. Does your company (Do you) currently use collision avoidance systems?

No (please continue to Question 8a)
Yes (please answer the questions on pages 21-22)

8a. Did your company (Did you) ever use this technology in the past?

No (please continue to Question 9)
Yes (please indicate the year(s) the technology was in use and why it was discontinued, then continue to Question 9).

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9. Does your company (Do you) currently use computer-aided routing and/or dispatching?

No (please continue to Question 9a)
Yes (please answer the questions on pages 23-24)

9a. Did your company (Did you) ever use this technology in the past?

No (please continue to Question 10)
Yes (please indicate the year(s) the technology was in use and why it was discontinued, then continue to Question 10).

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10. Does your company (Do you) currently use maintenance tracking software?

No (please continue to Question 10a)
Yes (please answer the questions on pages 25-26)

10a. Did your company (Did you) ever use this technology in the past?

No (please continue to Question 21)
Yes (please indicate the year(s) the technology was in use and why it was discontinued, then continue to Question 21).

____

____

TECHNOLOGY ADOPTION FACTORS

Please state approximately when your company (you) started using/implementing cellular phones for communications between dispatcher and driver(s), and, if applicable, when the implementation was completed. If the implementation is still in process, please estimate when completion is expected. Also, please indicate the percent of your vehicle fleet you have equipped with cellular phones for communications between dispatcher and driver(s).

Technology	Starting Date (month/year)	Completion Date (month/year)	Percent of Fleet Equipped
11. Cellular phones for communications between dispatcher and driver(s)			

Please rate the following technology adoption factors on a 1 to 5 scale (1 = strongly disagree; 5 = strongly agree)

		1 = Strongly Disagree; 5 = Strongly Agree				
11a.	Using cellular phone communications between dispatcher and driver(s) enhances our (my) efficiency.	1	2	3	4	5
11b.	I think cellular phone communications between dispatcher and driver(s) fits well with the way we (I) work.	1	2	3	4	5
11c.	Learning to interact with cellular phone communications between dispatcher and driver(s) was easy for us (me).	1	2	3	4	5
11d.	We were (I was) able to try out the cellular phone communications between dispatcher and driver(s) on a limited basis before we (I) decided to fully implement it.	1	2	3	4	5
11e.	We were (I was) able to observe other companies (drivers) using cellular phones before we (I) decided to try it.	1	2	3	4	5

		1 = Strongly Disagree; 5 = Strongly Agree				
11f.	We (I) think cellular phone communications between dispatcher and driver(s) fits into our (my) lifestyle.	1	2	3	4	5
11g.	It was easy for us (me) to become skillful at using cellular phone communications between dispatcher and driver(s).	1	2	3	4	5
11h.	Using cellular phone communications between dispatcher and driver(s) makes our (my) job/work easier.	1	2	3	4	5
11i.	Once in use, our (my) employees and/or customers could readily see and understand why we (I) chose to implement cellular phone communications between dispatcher and driver(s).	1	2	3	4	5
11j.	We were (I was) able to implement cellular phone communications between dispatcher and driver(s) in phases rather than all at once.	1	2	3	4	5

Please return to Question 2 on page 1.

Please state approximately when your company (you) started using/implementing satellite for communications between dispatcher and driver(s), and, if applicable, when the implementation was completed. If the implementation is still in process, please estimate when completion is expected. Also, please indicate the percent of your vehicle fleet you have equipped with satellite for communications between dispatcher and driver(s).

Technology	**Starting Date (month/year)**	**Completion Date (month/year)**	**Percent of Fleet Equipped**
12. Satellite communications between dispatcher and driver(s)			

Please rate the following technology adoption factors on a 1 to 5 scale (1 = strongly disagree; 5 = strongly agree)

		1 = Strongly Disagree; 5 = Strongly Agree				
12a.	Using satellite communications between dispatcher and driver(s) enhances our (my) efficiency.	1	2	3	4	5
12b.	I think using satellite communications between dispatcher and driver(s) fits well with the way we (I) work.	1	2	3	4	5
12c.	Learning to interact with satellite communications between dispatcher and driver(s) was easy for us (me).	1	2	3	4	5

12d.	We were (I was) able to try out using satellite communications between dispatcher and driver(s) on a limited basis before we (I) decided to fully implement it.	1	2	3	4	5
12e.	We were (I was) able to observe other companies (drivers) using satellite communications between dispatcher and driver(s) before we (I) decided to try it.	1	2	3	4	5
12f.	We (I) think using satellite communications between dispatcher and driver(s) fits into our (my) lifestyle.	1	2	3	4	5
12g.	It was easy for us (me) to become skillful at using satellite communications between dispatcher and driver(s).	1	2	3	4	5
12h.	Using satellite communications between dispatcher and driver(s) makes our (my) job/work easier.	1	2	3	4	5
12i.	Once in use, our (my) employees and/or customers could readily see and understand why we (I) chose to implement using satellite communications between dispatcher and driver(s).	1	2	3	4	5
12j.	We were (I was) able to implement using satellite communications between dispatcher and driver(s) in phases rather than all at once.	1	2	3	4	5

Please return to Question 3 on page 2.

Please state approximately when your company (you) started using/implementing on-board or handheld computers for vehicle diagnostics, and, if applicable, when the implementation was completed. If the implementation is still in process, please estimate when completion is expected. Also, please indicate the percent of your vehicle fleet you have equipped with on-board or handheld computers for vehicle diagnostics.

Technology	**Starting Date (month/year)**	**Completion Date (month/year)**	**Percent of Fleet Equipped**
13. On-board or handheld computers for vehicle diagnostics			

Please rate the following technology adoption factors on a 1 to 5 scale
(1 = strongly disagree; 5 = strongly agree)

		1 = Strongly Disagree; 5 = Strongly Agree				
13a.	Using on-board or handheld computers for vehicle diagnostics enhances our (my) efficiency.	1	2	3	4	5
13b.	I think on-board or handheld computers for vehicle diagnostics fits well with the way we (I) work.	1	2	3	4	5
13c.	Learning to interact with on-board or handheld computers for vehicle diagnostics was easy for us (me).	1	2	3	4	5
13d.	We were (I was) able to try out the on-board or handheld computers for vehicle diagnostics on a limited basis before we (I) decided to fully implement it.	1	2	3	4	5

13e.	We were (I was) able to observe other companies (drivers) using on-board or handheld computers for vehicle diagnostics before we (I) decided to try it.	1	2	3	4	5
13f.	We (I) think on-board or handheld computers for vehicle diagnostics fit into our (my) lifestyle.	1	2	3	4	5
13g.	It was easy for us (me) to become skillful at using on-board or handheld computers for vehicle diagnostics .	1	2	3	4	5
13h.	Using on-board or handheld computers for vehicle diagnostics makes our (my) job/work easier.	1	2	3	4	5
13i.	Once in use, our (my) employees and/or customers could readily see and understand why we (I) chose to implement on-board or handheld computers for vehicle diagnostics .	1	2	3	4	5
13j.	We were (I was) able to implement on-board or handheld computers for vehicle diagnostics in phases rather than all at once.	1	2	3	4	5

Please return to Question 4 on page 2.

Please state approximately when your company (you) started using/implementing on-board or handheld computers for driver performance, and, if applicable, when the implementation was completed. If the implementation is still in process, please estimate when completion is expected. Also, please indicate the percent of your vehicle fleet you have equipped with on-board or handheld computers for driver performance.

Technology	Starting Date (month/year)	Completion Date (month/year)	Percent of Fleet Equipped
14. On-board or handheld computers for driver performance			

Please rate the following technology adoption factors on a 1 to 5 scale (1 = strongly disagree; 5 = strongly agree)

		1 = Strongly Disagree; 5 = Strongly Agree				
14a.	Using on-board or handheld computers for driver performance enhances our (my) efficiency.	1	2	3	4	5
14b.	I think on-board or handheld computers for driver performance fits well with the way we (I) work.	1	2	3	4	5
14c.	Learning to interact with on-board or handheld computers for driver performance was easy for us (me).	1	2	3	4	5
14d.	We were (I was) able to try out the on-board or handheld computers for driver performance on a limited basis before we (I) decided to fully implement it.	1	2	3	4	5

14e.	We were (I was) able to observe other companies (drivers) using on-board or handheld computers for driver performance before we (I) decided to try it.	1	2	3	4	5
14f.	We (I) think on-board or handheld computers for driver performance fit into our (my) lifestyle.	1	2	3	4	5
14g.	It was easy for us (me) to become skillful at using on-board or handheld computers for driver performance.	1	2	3	4	5
14h.	Using on-board or handheld computers for driver performance makes our (my) job/work easier.	1	2	3	4	5
14i.	Once in use, our (my) employees and/or customers could readily see and understand why we (I) chose to implement on-board or handheld computers for driver performance.	1	2	3	4	5
14j.	We were (I was) able to implement on-board or handheld computers for driver performance in phases rather than all at once.	1	2	3	4	5

Please return to Question 5 on page 3.

Please state approximately when your company (you) started using/implementing electronic logbooks for monitoring driver hours of service, and, if applicable, when the implementation was completed. If the implementation is still in process, please estimate when completion is expected. Also, please indicate the percent of your vehicle fleet you have equipped with electronic logbooks for monitoring driver hours of service.

Technology	Starting Date (month/year)	Completion Date (month/year)	Percent of Fleet Equipped
15. Electronic logbooks for monitoring driver hours of service			

Please rate the following technology adoption factors on a 1 to 5 scale (1 = strongly disagree; 5 = strongly agree)

		1 = Strongly Disagree; 5 = Strongly Agree				
15a.	Using electronic logbooks for monitoring driver hours of service enhances our (my) efficiency.	1	2	3	4	5
15b.	I think electronic logbooks for monitoring driver hours of service fits well with the way we (I) work.	1	2	3	4	5
15c.	Learning to interact with electronic logbooks for monitoring driver hours of service was easy for us (me).	1	2	3	4	5

15d.	We were (I was) able to try out the electronic logbooks for monitoring driver hours of service on a limited basis before we (I) decided to fully implement it.	1	2	3	4	5
15e.	We were (I was) able to observe other companies (drivers) using electronic logbooks for monitoring driver hours of service before we (I) decided to try it.	1	2	3	4	5
15f.	We (I) think electronic logbooks for monitoring driver hours of service fit into our (my) lifestyle.	1	2	3	4	5
15g.	It was easy for us (me) to become skillful at using electronic logbooks for monitoring driver hours of service.	1	2	3	4	5
15h.	Using electronic logbooks for monitoring driver hours of service makes our (my) job/work easier.	1	2	3	4	5
15i.	Once in use, our (my) employees and/or customers could readily see and understand why we (I) chose to implement electronic logbooks for monitoring driver hours of service.	1	2	3	4	5
15j.	We were (I was) able to implement electronic logbooks for monitoring driver hours of service in phases rather than all at once.	1	2	3	4	5

Please return to Question 6 on page 3.

Please state approximately when your company (you) started using/implementing transponders for toll booths, and, if applicable, when the implementation was completed. If the implementation is still in process, please estimate when completion is expected. Also, please indicate the percent of your vehicle fleet you have equipped with transponders for toll booths.

Technology	**Starting Date (month/year)**	**Completion Date (month/year)**	**Percent of Fleet Equipped**
16. Transponders for toll booths			

Please rate the following technology adoption factors on a 1 to 5 scale (1 = strongly disagree; 5 = strongly agree)

		1 = Strongly Disagree; 5 = Strongly Agree				
16a.	Using transponders for toll booths enhances our (my) efficiency.	1	2	3	4	5
16b.	I think transponders for toll booths fits well with the way we (I) work.	1	2	3	4	5
16c.	Learning to interact with transponders for toll booths was easy for us (me).	1	2	3	4	5
16d.	We were (I was) able to try out the transponders for toll booths on a limited basis before we (I) decided to fully implement it.	1	2	3	4	5
16e.	We were (I was) able to observe other companies (drivers) using transponders for toll booths before we (I) decided to try it.	1	2	3	4	5

16f.	We (I) think transponders for toll booths fit into our (my) lifestyle.	1	2	3	4	5
16g.	It was easy for us (me) to become skillful at using transponders for toll booths.	1	2	3	4	5
16h.	Using transponders for toll booths makes our (my) job/work easier.	1	2	3	4	5
16i.	Once in use, our (my) employees and/or customers could readily see and understand why we (I) chose to implement transponders for toll booths.	1	2	3	4	5
16j.	We were (I was) able to implement transponders for toll booths in phases rather than all at once.	1	2	3	4	5

Please return to Question 7 on page 4.

Please state approximately when your company (you) started using/implementing transponders for weigh stations (PrePass, NORPass, etc.), and, if applicable, when the implementation was completed. If the implementation is still in process, please estimate when completion is expected. Also, please indicate the percent of your vehicle fleet you have equipped with transponders for weigh stations (PrePass, NORPass, etc.).

Technology	**Starting Date (month/year)**	**Completion Date (month/year)**	**Percent of Fleet Equipped**
17. Transponders for weigh stations (PrePass, NorPASS, etc.)			

Please rate the following technology adoption factors on a 1 to 5 scale (1 = strongly disagree; 5 = strongly agree)

		1 = Strongly Disagree; 5 = Strongly Agree				
17a.	Using transponders for weigh stations (PrePass, NorPASS, etc.) enhances our (my) efficiency.	1	2	3	4	5
17b.	I think transponders for weigh stations (PrePass, NorPASS, etc.) fits well with the way we (I) work.	1	2	3	4	5
17c.	Learning to interact with transponders for weigh stations (PrePass, NorPASS, etc.) was easy for us (me).	1	2	3	4	5

17d.	We were (I was) able to try out the transponders for weigh stations (PrePass, NorPASS, etc.) on a limited basis before we (I) decided to fully implement it.	1	2	3	4	5
17e.	We were (I was) able to observe other companies (drivers) using transponders for weigh stations (PrePass, NorPASS, etc.) before we (I) decided to try it.	1	2	3	4	5
17f.	We (I) think transponders for weigh stations (PrePass, NorPASS, etc.) fit into our (my) lifestyle.	1	2	3	4	5
17g.	It was easy for us (me) to become skillful at using transponders for weigh stations (PrePass, NorPASS, etc.).	1	2	3	4	5
17h.	Using transponders for weigh stations (PrePass, NorPASS, etc.) makes our (my) job/work easier.	1	2	3	4	5
17i.	Once in use, our (my) employees and/or customers could readily see and understand why we (I) chose to implement transponders for weigh stations (PrePass, NorPASS, etc.).	1	2	3	4	5
17j.	We were (I was) able to implement transponders for weigh stations (PrePass, NorPASS, etc.) in phases rather than all at once.	1	2	3	4	5

Please return to Question 8 on page 4.

Please state approximately when your company (you) started using/implementing collision avoidance systems, and, if applicable, when the implementation was completed. If the implementation is still in process, please estimate when completion is expected. Also, please indicate the percent of your vehicle fleet you have equipped with collision avoidance systems.

Technology	**Starting Date (month/year)**	**Completion Date (month/year)**	**Percent of Fleet Equipped**
18. Collision avoidance system			

Please rate the following technology adoption factors on a 1 to 5 scale (1 = strongly disagree; 5 = strongly agree)

		1 = Strongly Disagree; 5 = Strongly Agree				
18a.	Using the collision avoidance system enhances our (my) efficiency.	1	2	3	4	5
18b.	I think the collision avoidance system fits well with the way we (I) work.	1	2	3	4	5
18c.	Learning to interact with the collision avoidance system was easy for us (me).	1	2	3	4	5
18d.	We were (I was) able to try out the collision avoidance system on a limited basis before we (I) decided to fully implement it.	1	2	3	4	5
18e.	We were (I was) able to observe other companies (drivers) using the collision avoidance system before we (I) decided to try it.	1	2	3	4	5

18f.	We (I) think the collision avoidance system fits into our (my) lifestyle.	1	2	3	4	5
18g.	It was easy for us (me) to become skillful at using the collision avoidance system.	1	2	3	4	5
18h.	Using the collision avoidance system makes our (my) job/work easier.	1	2	3	4	5
18i.	Once in use, our (my) employees and/or customers could readily see and understand why we (I) chose to implement the collision avoidance system.	1	2	3	4	5
18j.	We were (I was) able to implement the collision avoidance system in phases rather than all at once.	1	2	3	4	5

Please return to Question 9 on page 5.

Please state approximately when your company (you) started using/implementing computer aided routing and/or dispatching, and, if applicable, when the implementation was completed. If the implementation is still in process, please estimate when completion is expected. Also, please indicate the percent of your vehicle fleet you have equipped with computer aided routing and/or dispatching.

Technology	**Starting Date (month/year)**	**Completion Date (month/year)**	**Percent of Fleet Equipped**
19. Computer aided routing and/or dispatching			

Please rate the following technology adoption factors on a 1 to 5 scale (1 = strongly disagree; 5 = strongly agree)

		1 = Strongly Disagree; 5 = Strongly Agree				
19a.	Using computer aided routing and/or dispatching enhances our (my) efficiency.	1	2	3	4	5
19b.	I think computer aided routing and/or dispatching fits well with the way we (I) work.	1	2	3	4	5
19c.	Learning to interact with computer aided routing and/or dispatching was easy for us (me).	1	2	3	4	5
19d.	We were (I was) able to try out computer aided routing and/or dispatching on a limited basis before we (I) decided to fully implement it.	1	2	3	4	5
19e.	We were (I was) able to observe other companies (drivers) using computer aided routing and/or dispatching before we (I) decided to try it.	1	2	3	4	5

19f.	We (I) think computer aided routing and/or dispatching fits into our (my) lifestyle.	1	2	3	4	5
19g.	It was easy for us (me) to become skillful at using computer aided routing and/or dispatching.	1	2	3	4	5
19h.	Using computer aided routing and/or dispatching makes our (my) job/work easier.	1	2	3	4	5
19i.	Once in use, our (my) employees and/or customers could readily see and understand why we (I) chose to implement computer aided routing and/or dispatching .	1	2	3	4	5
19j.	We were (I was) able to implement computer aided routing and/or dispatching in phases rather than all at once.	1	2	3	4	5

Please return to Question 10 on page 5.

Please state approximately when your company (you) started using/implementing maintenance tracking software, and, if applicable, when the implementation was completed. If the implementation is still in process, please estimate when completion is expected. Also, please indicate the percent of your vehicle fleet you have equipped with maintenance tracking software.

Technology	**Starting Date (month/year)**	**Completion Date (month/year)**	**Percent of Fleet Equipped**
20. Maintenance tracking software			

Please rate the following technology adoption factors on a 1 to 5 scale (1 = strongly disagree; 5 = strongly agree)

		1 = Strongly Disagree; 5 = Strongly Agree				
20a.	Using maintenance tracking software enhances our (my) efficiency.	1	2	3	4	5
20b.	I think maintenance tracking software fits well with the way we (I) work.	1	2	3	4	5
20c.	Learning to interact with maintenance tracking software was easy for us (me).	1	2	3	4	5
20d.	We were (I was) able to try out maintenance tracking software on a limited basis before we (I) decided to fully implement it.	1	2	3	4	5
20e.	We were (I was) able to observe other companies (drivers) using maintenance tracking software before we (I) decided to try it.	1	2	3	4	5

20f.	We (I) think maintenance tracking software fits into our (my) lifestyle.	1	2	3	4	5
20g.	It was easy for us (me) to become skillful at using maintenance tracking software.	1	2	3	4	5
20h.	Using maintenance tracking software makes our (my) job/work easier.	1	2	3	4	5
20i.	Once in use, our (my) employees and/or customers could readily see and understand why we (I) chose to implement maintenance tracking software.	1	2	3	4	5
20j.	We were (I was) able to implement maintenance tracking software in phases rather than all at once.	1	2	3	4	5

Please continue to the next page.

DEMOGRAPHIC INFORMATION

21. How many trucks/buses, tractors, and/or trailers does your company (do you) operate?

_____ straight trucks/buses
_____ tractors
_____ trailers

22. If applicable, how many drivers does your company (do you) use?

_____ company drivers
_____ independent contractors

23. Is your company (Are you) primarily truckload or less-than-truckload, private or for-hire?

truckload	or	less-than-truckload
private	or	for-hire

24. What type of cargo does your company (do you) generally haul?

____

25. How long has your company (you) been in business (commercial vehicle transportation-related)?

______ years

Please feel free to provide any comments you may have.

Thank you for your assistance.

Vita for Brenda M. Lantz

NDSU/UGPTI Transportation Safety Systems Center
1536 Cole Blvd, Suite 140
Lakewood, CO 80401

Phone: 720.238.0070
Fax: 720.238.0064
brenda.lantz@ndsu.edu

EXPERTISE

Brenda Lantz is the Program Director for the Transportation Safety Systems Center branch of North Dakota State University's Upper Great Plains Transportation Institute (NDSU/UGPTI). The Center is responsible for software development for commercial vehicle safety enforcement programs, as well as safety-related research and analysis (http://www.ugpti.org/tssc/).

Dr. Lantz has more than 15 years of experience in transportation research, primarily in the commercial vehicle safety systems field, and has worked extensively with both government and private industry agencies.

SELECTED PROJECTS / PUBLICATIONS

Commercial Vehicle Inspection and Investigative Systems Software Development. As Program Director of the NDSU/UGPTI Transportation Safety Systems Center, Dr. Lantz manages a team responsible for the successful development and delivery of inspection and investigative commercial vehicle safety systems in use by the Federal Motor Carrier Safety Administration (FMCSA) and State enforcement agencies nationwide.

Commercial Motor Vehicle Driver Risk Factors Study. Initiated Summer 2006, this project examines a wide array of driver and situational safety factors and determines the prevalence of these factors and increased or decreased crash and incident risk associated with them.

Development and Implementation of a Driver Safety History Indicator into the Roadside Inspection Selection System. Completed Spring 2006, the main objective of this project was to integrate the carrier driver conviction measure (developed through a separate project) into the current Inspection Selection System, and evaluate its real-world effectiveness in reducing crashes. Published in the Transportation Research Record, 2006.

The Integration of the Motor Carrier Safety Status (SafeStat) Measurement System into the Roadside Inspection Selection System. Published in the Transportation Research Record, 2000.

EDUCATION

Doctoral Degree, Business Administration, Supply Chain and Information Systems, 2006
The Pennsylvania State University, State College, PA

Master of Science Degree, Applied Statistics, with Transportation Research emphasis, 1994
North Dakota State University, Fargo, ND

Bachelor of Science Degree, Sociology, with Research emphasis, 1990
Minors: Business and Psychology
North Dakota State University, Fargo, ND