ABSTRACT

Title of Document: RISK MITIGATION IN THE SUPPLY CHAIN: EXAMINING THE ROLE OF IT INVESTMENT TO MANAGE SAFETY PERFORMANCE

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Safety management in the supply chain isan interesting topic . The existence of unexpected supply chain events makes supply chain decision making difficult. To improve their response to unexpected events such as natural disasters or workplace accidents, managers are beginning to examine the link between information technology (IT) and safety in the supply chain.

This dissertation examines the IT and safety link in three main ways. First, in the chapter entitled, "IT Investment and Safety: An Examination of The Impact of Information Technology on Safety Performance in a High Reliability Organization," drawing upon the work of Bharadwaj (2000), a theoretical modelthat links a firm's investment in IT resources to safety is developed. This model is empirically tested. A key finding is that physical IT resources, human IT resources, and growth in IT resources do contribute to safety performance.

The second way that the IT and safety link is examined is through a U.S. Department of Transportation sponsored survey. In the chapter entitled, "Technology Adoption Patterns in the U.S. Motor Carrier Industry," a national survey is conducted to examine the safety technology adoption practices of larger trucking firms. The survey consists of twenty-six leading-edge safety technologies. A key finding is thatlarger trucking firms and firms that travel long distances are leaders in IT investment.

Drawing on the resource-based view of the firm (RBV), the third way that the IT and safety link is examined is in the chapter entitled "Driving for Safety: An Examination of Safety Technology Adoption and Firm Safety Performance in the U.S. Motor Carrier Industry." The RBV framework describes how a firm's internal resources may be used to improve firm performance. Based on an over 50% survey response rate, a key finding is thatsafety technology resources do contribute to safety performance. It is also discovered that if the firm's top management team is knowledgeable about safety technology practices, the effect of safety technology resources on safety performance increases. Similarly, if the firm's IT staff has technology project management skills, the effect of safety technology resources on safety performance increases.

RISK MITIGATION IN THE SUPPLY CHAIN: EXAMINING THE ROLE OF IT INVESTMENT TO MANAGE SAFETY PERFORMANCE

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Dedication

This dissertation is dedicated to my wife, Jill, my parents Jeff, Ruth, Paul, and Janet, and my sister and brother, Julie and AdamTheir love and support made all of this possible.

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In conclusion, the views expressed in this dissertation are of the author. This dissertation is not in any way intended to reflect the views of the U.S. Department of Transportation or any other agency.

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Chapter 1: Introduction

Background

The topic of safety performance in supply chain management is receiving increased attention (Kelindorder and Saad 2005; Cacinato 2004; Chopra and Sodhi 2004;and Christopher and Lee 2004). Supply chain managers are very interested in the topic of safety performance because of the many unexpected and unpredictable events that may face the firm including situations such as hurricanes, terrorist attacks, labor strikes and workplace accidents (Christoper and Lee 2004). The existence of these unexpected events induces a level of nervousness and chaos that makes it difficult to make sound decisions in the supply chain. Supply chain managers are beginning to take actions and intervene to address these supply chain disruptions. For example, if a sales team believes that order cycle and order fulfillment times are not reliable, the sales team will devise their own strategy to deal with this problem. Their safety performance strategy could include maintaining higher levels of safety stocks. However, this strategy can lead to other forms of risk including material obsolescence risk. Therefore, in order to instill a higher level of confidence, supply chain managers are looking for proactive ways to develop greater visibility and control into the entire supply chain in the form ofsafety strategies.

To achieve a greater level of visibility and control across the supply chain, supply chain managers are increasingly making investments into information technology resources to manage their exposure to unsafe situations.

Investment into information technology resources can enable the supply chain manager to heed warnings and to solve problems (Marcus and Nichols 1999). A supply chain manager requires safety resources that can facilitate the firm's ability to detect in advance potential failures of physical and human systems that would normally place the firm in catastrophic situations. Through the investment in safety resources such as information technology, the supply chain manager can reduce the firm's involvement in catastrophic incidents and hence improve the firm's supply chain performance.

Purpose of Dissertation

This dissertation seeks to examine how investment in information technology resources enables the firm to improve its safety performance. While recent research has begun to provide a conceptual and theoretical basis for the nexus of information technology and safety performance, there has been scant attention paid to how information technology drives the firm's safety performance. Some information technology studies such as Le Blanc and Kozar (1990), Palvia, Perkins, and Zeltman (1992), and Grabowski and Roberts (1999) provide us with specific insights into how information technology can help mitigate the risk that a member of the supply chain may confront as it engages in business activities (e.g., high accident rates and other safety problems). However, there is a gap in the literature in terms of how information technology resources contribute to safety performance.

Most of the literature to date has only examined how firm safety performance, as an explanatory variable, affects the use of the IT systems (Le Blanc and Kozar 1990). Therefore, it is important to show that the supply chain member's investment in IT resources is a driver of safety performance.

The Conceptual Problem That Dissertation Aims to Solve

This dissertation seeks to solve the IT investment and safety performance conceptual problem by establishing both a theoretical and empirical link between these two constructs. To date, there has been very little attention paid to how information technology reduces a supply chain member's involvement in potentially unsafe situations. Some information systems studies such as Weill, Subramani, and Broadbent (2002), Le Blanc and Kozar (1990), Palvia, Perkins, and Zeltman (1992), and Graboski and Roberts (1999) provide us with specific insights into how information technology can help mitigate the firm's involvement in unsafe situations as it engages in business activities (e.g., network security breaches, natural disasters, terrorist attacks, power outages, and high crash rates). However, there is a gap in the literature in terms of how investment in information technology resources reduces the firm's involvement in unsafe situations in the context of supply chain management. Therefore, it is important to show that IT investment reduces the supply chain member's safety performance.

Four Problems That This Dissertation Aims to Solve

Problem #1: Establishment of Theoretical Link: IT Investment Resources and Safety Performance.

This dissertation seeks to solve four problems. First, this dissertation will establish a theoretical link between the firm's investment in IT resources and firm safety performance. This dissertation will establish this link by drawing-upon the resource-based view of the firm which has been used by other information system researchers to understand the ever-increasing impact of information technology on firm performance. For example, the information systems literature has long noted the important impact of information technology on firm performance (Dedrick et al. 2003). Beginning with the work of Leavitt and Whisler (1958) and continuing in more recent studies, one stream of research has employed a production function approach from neoclassical economics to examine how information technology, as an input to production, increases productivity (Brynjolfsson and Hitt 1996; Dewan and Min 1997; Hitt and Brynjolfsson 1996). More recently, a second body of research has examined how IT impacts profitability (Bharadwaj 2000; Sanathanam and Hartono 2003; Zhu and Kraemer 2002). Although researchers have examined the effect of information technology investment on many measures of firm performance, few have explored the link between information technology and the firm's involvement in unsafe situations.

This dissertation will establish this link by adopting the RBV framework as proposed by Bharadwaj (2000) to theoretically and empirically explore how IT resources can contribute to improving the firm's safety performance. Additionally, this dissertation will also examine how the RBV framework can be extended to the safety management literature.

For example, Marcus and Nichols (1999) adopt the RBV framework to shed some light on how safety organizations utilize unique and difficult to copy resources to address safety and reliability issues. Therefore, this dissertation will show how a firm's IT investment resources can be used in the context of safety.

Problem #2: General IT Investment Resources and Safety Performance

The second problem that this dissertation will solve is to identify what are the specific IT investment resources that high reliability organizations (HROs) can use to manage its safety performance. While previous research has examined how information technology investment impacts firm performance, there has been very little research in terms of what are some disaggregate IT resources that impact HRO performance (Brynjolfsson and Hitt 1996; Dewan and Min 1997; Hitt and Brynjolfsson 1996). Previous studies such as Brynjolfsson and Hitt (1996), Dewan and Min (1997), and Hitt and Brynjolfsson (1996) have utilized IT investment aggregate data to understand how a firm' IT resources impact firm performance. It hasn't been until recently that some studies have begun to disaggregate the IT investment blackbox to understand the specific types of IT investment resources thatcontribute to firm performance. For example, through the use of Harte-Hanks market intelligence data, both Zhu and Kraemer (2002) and Forman (2005) begin to disaggregate the IT investment construct to understand what are some specific types of technologies that may lead to improvements in e-commerce performance or Internet technology adoption.

This dissertation will utilize Harte-Hanks' investment data to establish the linkage between disaggregate IT resources and firm safety performance. This dissertation will explain the theoretical relationship between disaggregate IT investment resources and firm safety performance. For example, firms that invest in mobile IT resources may be able to increase the HRO performance because of how mobile IT can provide real-time access from the firm's remote locations to its central operations (Hubbard 2003). Therefore, it is important to open-up the IT investment blackbox so that HROs can begin to understand the specific types of information technology resources that may impact firm safety performance. As pointed out by Orlikowski and Iacono (2001), the IT resource is constantly changing and future research is needed to understand the components that make-up IT systems.

Problem #3: Identification of Best Safety Technology Resource Practices

The third problem that this dissertation will solve is to identify what are some of the best safety technology resource practices among large firms in the U.S. Motor Carrier Industry Some researchers have pointed out that a potential criticism of only examining general purpose IT resources is that we are only gaining a limited understanding of how the specific attributes of information technology may be related to firm performance. Many organizations make investments into general purpose IT technologies and then the organization coalesces these commercial off-the-shelf (COTS) technology solutions into specific IT resources (Mata et al 1995; and Bharadwaj 2001).

To respond to this concern, some researchers have begun to examine how specific information technology applications impacts firm performance. For example, Zhu and Kraemer (2002) and Forman (2005) examine how e-commerce applications and LAN applications impact firm performance. Moreover, Hubbard (2003) conducted an examination of how on-board computers (OBCs) impacts firm performance in the U.S. Motor Carrier Industry.

Through the development of a unique and comprehensive survey instrument, this dissertation will identify the safety specific technology resources that large firms are adopting in the U.S. Motor Carrier Industry. This information can then be used to assist medium and smaller firms to understand the potential benefits and limitation of safety technology resources. From both a managerial and public policy perspective, it is important to document and disseminate information about which safety technologies may have the greatest impact on safety performance. This dissertation may serve as a guide to managers and safety management regulators about the appropriate steps to use safety technology resources.

Problem #4: Relationship Between Safety Technology Resources and Safety Performance.

The fourth problem that this dissertation will solve is to identify what is the theoretical and empirical relationship between safety technology investment and safety performance. This study will also examine how safety technology practices may enhance the effect of safety IT investment to safety performance.

Therefore, this dissertation will extend upon previous IT investment research by examining how safety technology practices enhances the effect of IT investment on firm performance.

Contributions of Dissertation

There are several potential contributions that this dissertation will make to the academic and managerial literatures. First, to the best of our knowledge, this is the first empirical study examining how IT investment impacts safety performance. Further, this dissertation is one of the first studies to make the IT investment linkage with safety performance by opening up the information technology black-box (Orlikowski and Iacono 2001). Previous studies have only taken an aggregate perspective of how information technology affects firm performance. Additionally, this dissertation takes a multi-method approach to open-up the information technology blackbox by both examining general purpose information technology resources and safety specific information technology resources. As a result, we anticipate that our findings will complement and contribute to the stream of information systems and supply chain management literature that is examining the impact of IT investment on firm productivity and performance.

From a managerial perspective, this dissertation makes several contributions. First, this dissertation addresses how supply chain organizations can utilize IT investment resources to address an issue that is under constant public scrutiny – safety performance (Corsi and Fanara 1988).

Second, this dissertation’s findings can assist managers to identity what are the best safety technology practices that motor carrier firms should invest in to improve safety performance. Therefore, motor carrier safety professionals will be able to learn if safety technology investments have an effect on safety performance.

Chapter 2: IT Investment and Safety: An Examination of the Impact of Information Technology on Safety Performance in a High Reliability Organization

Introduction

A high reliability organization (HRO) is defined as an organization that prioritizes safety and reliability as goals to enhance their safe operations. HROs typically operate nearly error-free for long periods of time (Grabowski and Roberts 1999; Roberts 1990). Further, HROs often utilize highly complex technologies which are highly interdependent and rarely experience events which lead to catastrophic consequences (Roberts, Stout, and Halpern 1994). However, within HROs, there are situations in which small errors can propagate into grave consequences (Grabowski and Roberts 1999). The U.S. Space Industry is one setting which exhibits many of the characteristics that are found in an HRO. For example, several years ago, the U.S. Space Industry experienced a tragedy when the Challenger Shuttle exploded because of the failure of a critical component -- a poorly designed O-Ring which failed during its low-temperature launch. Even though NASA contractors manufactured this part several years prior to the Challenger disaster, the engineers did not understand the ramifications of how a small design flaw could contribute to this awful event. Therefore, this example illustrates the importance of understanding how the utilization of a high reliability organization's internal resources contributes to safety performance.

The U.S. Motor Carrier Industry is another setting which exhibits high reliability organizational characteristics. As described by the U.S. Department of Transportation, there are over 400,000 crashes resulting over 100,000 injuries or fatalities involving motor vehicles in the United States (U.S. Department of Transportation 2006). As a result, safety performance is very important to motor carrier firms because of the catastrophic consequences of not operating error-free. Indeed, federal and state government regulations require firms in this industry to adhere to good safety performance (Corsi and Fanara 1988). There are also negative consequences to the firms in this industry if they don't adhere to good safety and reliability practices including higher insurance costs, financial and legal liabilities, and loss of corporate goodwill (Corsi, Fanara, and Jarrell 1988). As a result, poor safety and reliability performance results in a negative reputation which will make it difficult for motor carrier firms to attract customers who will want to conduct business with it. Finally, by not achieving good safety performance, motor carrier firms will have difficulty recruiting employees because of the poor corporate image of the firm.

To keep high reliability organizations (HRO), such as motor carrier firms, in a zone of safety requires that the firm have the resources it needs to heed warnings and solve problems (Marcus and Nichols 1999). An HRO requires safety resources that will enable it to detect in advance potential failures of physical and human systems that would normally place it in catastrophic situations.

Through the investment in safety resources, the HRO can reduce its involvement in catastrophic incidents and hence improve the firm's overall performance.

It is important to understand the drivers of safety performance in high reliability organizations (HROs). Researchers are interested in studying HROs because while the probability of error is low the consequences are high (Grabowski and Roberts 1999). To understand how these organizations can improve their safety performance, the HRO literature has focused on studying the organizational factors that could impact safety. For example, Marcus and Nichols (1999) utilize a case study approach to understand how resources can be used to prevent safety problems. Also through the use of a case study, Roberts, Stout, and Halpern (1994) shed light on how faulty decision-making can lead to catastrophic consequences. Roberts and Bea (2001) provide recommendations on what firms can do to enhance reliability in HROs. Lastly, Grabowksi and Roberts (1999) indicate that HROs should adopt risk mitigation processes to enhance safety and reliability. While the HRO literature has focused on the drivers of safety utilizing the case study method, the literature has not examined the drivers of safety performance to enhance risk avoidance by adopting a statistical analysis.

There is a stream of motor carrier research that addresses the link between motor carrier safety management and safety performance. This stream of research has examined the connection between motor carrier management practices and crash rates (Mejza and Corsi 1999; and Mejza, Barnard, Corsi and Keane 2003).

Crum and Morrow (2002) empirically examined motor carrier scheduling practices to link greater driver fatigue with a greater likelihood of crashes. An important finding is that motor carrier practices to create driver-friendly schedules would have a positive effect on lowering crash rates. Corsi and Fanara (1998) provide empirical evidence that driver turnover rates and driver hours of service effect crash rates. Thus, improved safety practices to improve driver working conditions would presumably have a positive impact on lowering crash rates for individual motor carrier firms.

One important and relatively unexplored driver of safety performance is the investment in information technology. While information systems (IS) researchers are acquiring an ever-increasing understanding of the impact of information technology on firm performance, it is important that IS researchers include specific measures of a firm's safety performance as a dimension of overall firm performance. The information systems literature has long noted the important impact of information technology on firm performance (Dedrick et al. 2003). Beginning with the work of Leavitt and Whisler (1958) and continuing in more recent studies, one stream of research has employed a production function approach from neoclassical economics to examine how information technology, as an input to production, increases productivity (Brynjolfsson and Hitt 1996; Dewan and Min 1997; Hitt and Brynjolfsson 1996). More recently, a second body of research has examined how IT impacts profitability (Bharadawaj 2000; Sanathanam and Hartono 2003; Zhu and Kraemer 2002).

Although researchers have examined the effect of information technology investment on many measures of firm performance, few have explored the link between information technology and the firm's safety performance.

While recent research provides an important conceptual and theoretical basis for the nexus of information technology and high reliability organizations, there has been very little attention paid to how information technology contributes to firm safety performance. Weill, Subramani, and Broadbent (2002) suggest that it is increasingly important for the firm to create firewalls, policies for remote access, and password encryption systems to protect customer data from potentially malicious security breaches. Le Blanc and Kozar (1990) provide empirical evidence that decision support systems can mitigate the firm's involvement in maritime crashes. In a case study of Federal Express Corporation, Palvia, Perkins, and Zeltman (1992) provide anecdotal evidence that ERP systems can assist the firm with managing the safety performance of its employees and vehicles. However, there is a gap in the literature in terms of how investment in information technology contributes to safety performance in the context of high reliability organizations. Therefore, it is important to show that IT investment improves safety performance using a measure of the number of crashes that the firm was involved in as the dependent variable of interest.

The contribution of this study is to develop and empirically test a model of IT investment as a safety resource to improve an HRO's safety performance.

While previous research linking IT investment to firm performance has predominantly used a neoclassical economics or process-oriented approach (Barua et al. 1995; Hitt 1999), this study adopts the resource based view (RBV) of the firm (Bharadwaj 2000; Mata, Fuerst, and Barney 1995) to examine how IT can serve a resource to improve an HRO's safety performance. This perspective provides a solid basis for developing hypotheses on the impact of information technology on HRO safety performance. This theory is tested through the development of an original dataset drawn from the U.S. Motor Carrier Industry. This industry is well suited to this study given the paramount importance of improving safety performance of motor carrier firms. If amotor carrier firm is involved in a crash, there are catastrophic consequences including loss of life.

The remainder of the chapter is structured as follows. Section 2 provides an overview of the resource-based view and the development of several hypotheses on this basis. Section 3 describes the data and methodology. Section 4 presents an analysis of results, followed by discussion (Section 5) and conclusions (Section 6).

Theoretical Background and Hypotheses Development

A crash is one important type of safety performance problem thatan HRO experiences. An HRO may become involved in a crash especially when uncertain situations arise because it does not pay attention to the warning signs of impending failures of either its internal resources (i.e., human resources and physical resources) and/or its external environment (Mitroff, Shrivastava, and Udwadia 1987).

In an HRO, the firm experiences a crash because its employees fail to coordinate effectively in uncertain situations (Roberts 1990). For example, numerous National Transportation Safety Board investigations show that a large percentage of aircraft accidents happen when flight crews lose situational awareness. Similarly, an HRO experiences a crash because of the failure of its physical resources. An HRO utilizes advanced physical resources that can result in far reaching negative consequences should technological difficulties arise (Roberts 1990). Lastly the external environment may cause unexpected events to occur and this may impact crashes.

It is expected that an HRO's investment in information technology can serve as a safety resource that will enable the firm to improve its safety performance. For example, information technology is important in the context of software development projects where coordinating human and physical resources is especially important to prevent firm performance problems in terms of completinga project on-time, within budget, and meeting the user's requirements (Nidumolu 1995). To mitigate against software development performance risk, Nidumolu (1995) points out that information technology can be used to facilitate both horizontal and vertical coordination which can be used to reduce uncertainty in the development of large-scale software development projects. Moreover, Weill, Subramani, and Broadbent (2002) provide examples of firms thatinvest in IT-enabled security and safety resources to prevent uncertain situations from arising which can jeopardize the firm's "brand, reputation, data, equipment and revenue stream."

Lastly, Roberts (1990) shows thatinformation technology is also being used as a means to coordinate safety activities in high reliability organizations.

Following the theoretical perspectives in the literature in the fields of information systems and high reliability organizations, the resource-based view (RBV) is adopted as the theoretical basis for this study (Bharadwaj 2000; and Marcus and Nichols 1999). As has been pointed out by Barney (1991), Bharadwaj (2000), Zhu and Kraemer (2002), Sambamurthy et al (2003) and Wade and Hulland (2004), a key postulate of RBV is that the firm's resources are valuable, scarce, and imperfectly imitable. As pointed out by Eisenhardt and Martin (2000), physical, human, and organizational resources are used to implement value-creating strategies. Previous high reliability organization research is also integrated into this study to explain how in situations of resource availability, an HRO is able to improve its safety performance (Marcus and Nichols 1999).

Specifically, this dissertation draws upon the work of Bharadwaj (2000) who adopts the RBV perspective in the context of IT investment and firm performance. Bharadwaj (2000) describes that a firm's investment in tangible IT resources can impact firm performance. The first tangible IT resource that Bharadwaj (2000) identifies as critical to the performance of the firm is its physical IT resources. Specifically, the firm's physical IT resources include the hardware and operating systems, network and telecommunication technologies, and shared databases services (ERP applications, email, and videoconferencing services).

Through the use of these core physical IT resources, the firm can improve its safety performance by: monitoring its surroundings as a means to reduce the amount of uncertainty that may arise inside the organization or in the external environment; building and utilizing knowledge-based systems which can increase the absorptive capacity of the firm which is important to facilitate decision-making activities; and sharing resources that are available in one part of the part of the organization with other business units and departments. Therefore, consistent with Bharadwaj (2000), it is suggested thatan HRO's physical IT resources can contribute to improved safety performance.

The second tangible IT resource that Bharadwaj (2000) identifies as critical to firm performance is the firm's human IT resources. The firm's human IT resources consist of its top management team, managerial IT personnel, and technical IT personnel (e.g., programmers, system administrators, business analysts, etc). The human IT resource is the glue that binds the firm's physical IT resources together with the firm's business processes. Specifically, the human IT resources: 1) maintains the firm's physical IT resources; 2) develops and customizes physical IT resources to support advanced applications; and 3) integrates the firm's physical IT resources into the business processes of the firm (Armstrong and Sambamurthy 1999). Through the use of the firm's human IT resources, the firm can rapidly respond to uncertainty either within its internal operations or in the business environment to take advantage of opportunities or mitigate potential threats.

Consistent with Bharadwaj (2000), this dissertation proposes thatan HRO's human IT resources can configure its physical IT resources to improve safety performance.

A third resource that it is important to a HRO's safety performance is the renewal of its tangible resources (Zhu and Kraemer 2002). Drawing-upon the dynamic capabilities perspective (DCP), Zhu and Kraemer (2002) integrate the RBV framework with the DCP perspective to shed light on how important it is for the firm to renew and reinvest in new technological resources to replace outdated and obsolete technological resources. Therefore, consistent with Zhu and Kraemer (2002), the RBV framework is augmented with the DCP perspective to suggest that an HRO can improve its safety performance byreplacing and/or updating its IT resources.

Next, specific hypotheses are developed based upon both the resource-based theory of the firm and the dynamic capabilities perspective.

IT Resources and the Firm's Safety Performance

Physical IT Resources and the Firm's Safety Performance

The first tangible IT resource that is important to high reliability organizations is physical IT resources. First, a high reliability organization (HRO) invests in physical IT resources because it provides the firm with the ability to monitor its surroundings to reduce the amount of uncertainty that may arise inside the organization or in the external environment (Barua et al 2004; Kayworth, Chatterjee, and Sambamurthy 2001; and Broadbent and Weill 1997). To respond to rapidly changing business and environmental conditions, an HRO invests in physical IT resources so that it can collect data and information about the organization's internal and external activities to become alerted to unsafe situations (Kayworth et al 2001). For instance, an HRO can leverage the data-warehousing resources that are provided by its physical IT resources to collect information about how its employees and physical assets are performing as a means to make better safety management decisions (Cooper et al 2000). For example, in the U.S. Motor Carrier Industry, an HRO's investment in physical IT resources can be used to collect data on how many hours the firm's employees have been driving. If the driver has been operating the HRO's equipment beyond acceptable limits, then the HRO can immediately become alerted to this violation and sanction the employee in real-time. This example illustrates the real-time safety performance alerts that are made possible through the use of physical IT resources. The data that is collected through the use of physical IT resources can also enable the HRO to comply with the data and information requirements of safety government regulators (Broadbent and Weill 1997).

Second, the HRO can invest in physical IT resources to increase the organization's absorptive capacity and knowledge-based capabilities to support safety decision-making activities (Fichman 2001; and Armstrong and Sambamurthy 1999). For instance, Alavi and Leidner (2001) describe how knowledge management systems increase knowledge creation because physical IT resources helps the firm store, retrieve, transfer, and apply information to the knowledge creation process. Physical IT resources can provide immediate access to information about the firm's internal and external environment which enables the HRO to rapidly and fiercely respond to safety problems. Rapid decision-making is made by possible through the use of physical IT resources such as computer-supported collaborative work (CSCW) technology (Orlikowski and Barley 2001). High reliability organizations use physical IT resources to electronically communicate and collaborate on group-oriented safety situations because of the higher knowledge and communication requirements of these high velocity team-oriented tasks (e.g., videoconferencing, email, and collaborative software applications) (Grabowski and Roberts 1999). For example, in the U.S. Motor Carrier Industry, many HROs are increasingly adopting mayday systems that are used to coordinate emergency response teams to address crash situations that can turn into catastrophic environmental situations.

Lastly, an HRO can achieve economies of scale and scope from its investment in physical IT resources (Sambamurthy et al 2003).

The investment in physical IT resources requires a tremendous amount of time, development effort, and experimental learning (Bharadwaj 2000; Broadbent and Weill 1997; and Weill, Subramani, and Broadbent 2002). The HRO seeks to realize the benefits from its high capital investment in physical IT resources across multiple divisions within the firm. An HRO can realize increased benefits from its physical IT investment resources by applying the lessons learned from implementing physical IT resources in one business unit to the other business units in the organization (Kayworth et al 2001). One implementation benefit is that an HRO may become more agile and operationally efficient based on these physical IT resource knowledge sharing efforts. Finally, an HRO can derive proprietary advantages from its physical IT resources (Mata et al 1995).

The HRO's physical IT resources can play a prominent role in improving its safety performance. First, the HRO's physical IT resources serve as the initial layer upon which the firm can develop, build, implement and host safety specific software applications and telecommunications technology solutions thatcan improve the safety performance of the HRO (Fichman 2005; Palvia, Perkins, and Zeltmann 1992; and Roberts 1990). For example, Palvia, Perkins, and Zeltmann (1992) provide anecdotal evidence of how Federal Express Corporation was able to build safety performance software applications that collects all job-related injuries and responses into its enterprise resource planning (ERP) system.

Federal Express Corporation's ERP system "interfaces with the Federal Express risk management system, drug testing system, the aircrew assignment system, and the aircraft with a balance system to ensure that all government and company policies are followed." Federal Express is able to comply with many of the federal government's safety performance requirements in part because of the coordination, collaboration and knowledge-sharing capabilities of its ERP system. Housel, El Sawy, and Donovan (1986) report that a firm's underlying physical IT resources can facilitate the mobilization of a firm's key internal stakeholders to respond to safety crisis situations that requires quick, reliable, and comprehensive coordination and communication activities. In a business case study, Weill, Subramani, and Broadbent (2002) describe how leading firms prevent unsafe situations from arising. Leading-edge firms are able to enhance its initial physical IT resources with IT security applications such as firewalls and data and password encryption programs as a means to mitigate against unexpected events such as network security breaches, natural disasters, terrorist attacks, or power outages.

Second, an HRO can use physical IT resources to reduce its exposure or involvement in unsafe situations. In today's environment, physical IT resources are more mobile and therefore can alert and warn the HRO of impending situations of uncertainty.

For example, global positioning systems (GPS) is an example of a mobile physical IT resource that can be used by an HRO to increase its awareness of the movement of its corporate assets through physical space and away from unsafe working conditions (Hubbard 2003; and Lyytinen and Yoo 2002). For instance, GPS systems are used in the U.S. Maritime industry to monitor and route ships away from unsafe situations. The effectiveness of these types of technologies is provided by Le Blanc and Kozar (1990) who show that GPS technologies can prevent rammings and collisions from occurring in seaports. Decision-support systems and satellite communication technology are other examples of physical IT resources thatcan be u sed to provide advanced warning of critical or hazardous conditions (Le Blanc and Kozar 1990). Moreover, Gendreau and Potvin (2004) indicate thatGPS systems can be used to dynamically route the firm's assets and subsequently route emergency services if the firm finds itself in unsafe working conditions. Similarly, Nunamaker, Weber, and Chen (1989) and Belardo and Karwan (1986) discuss how group decision support systems (GDSS) can facilitate crisis situational planning and communication responses strategies across an organization. Indeed, state-of-the-art physical IT resources are also very important to HROsthat manage and support complex systems in the chemical and nuclear power industries (e.g., Union Carbide's chemical plant accident in Bhopal, India, and the nuclear reactor accident in Chernobyl) (Grabowski and Sanborn 2001; Roberts 1990).

Therefore, these examples point out that, through the investment in physical IT resources, an HRO is able to achieve greater agility to respond to rapidly changing environmental conditions (Chatterjee, Pacini, and Sambamurthy 2002; and Sambamurthy, Bharadwaj, and Grover 2003). An HRO with increased use of physical IT resources may be able to use its real-time physical IT systems to improve safety performance including preventing catastrophic situations from arising. These arguments lead to the following hypothesis:

H1: The greater the investment in physical IT resources the better the firm's safety performance.

Growth in Physical IT Resources and the Firm's Safety Performance

Up to this point, this dissertation has described how the resource based view provides insight into how investment in physical IT resources can contribute to an HRO's safety performance. At this time, we will enhance our theoretical perspective by integrating some key ideas from the dynamic capabilities perspective (DCP) to address the realities of HROs and rapid technological change (Zhu and Kraemer 2002; 2005). Specifically, the dynamic capabilities perspective refers to the activities associated with integrating, reconfiguring, and/or enhancingof resources to react to changes in the external environment (Teece et al 1997; and Eisenhardt and Martin 2000).

The dynamic capabilities framework is especially important in that it provides insight into how the episodic renewal of a resource can enable the firm to both address issues of technological change and the adoption of real-time performance advantages (Teece et al 1997). Therefore, viewed from a dynamic capabilities perspective, the second IT resource is the growth of an HRO's physical IT resources.

First, through the growth of its physical IT resources, an HRO will have access to current technologies that will enable it to rapidly respond to uncertainty in the internal and external environment (Teece et al 1997). The growth of an HRO's physical IT resources is very necessary because as new competence-destroying information technologies rapidly emerge, an HRO's previous physical IT resources become out-dated and ineffective (Agarwal and Sambamurthy 2002). Therefore, while previous physical IT resources can serve as an initial layer to build a HRO's technological infrastructure (Foreman 2005), prior physical IT resources often have an extremely limited shelf-life (Ang and Slaughter 2000) and therefore need to be enhanced with new IT resources (Zhu and Kraemer 2005; Foreman 2005). An HRO invests in newer technologies as a mechanism to achieve higher levels of coordination and communication to operate in the internal and external environment (Agarwal and Sambamurthy 2002). As a result, physical IT resources need to iteratively grow over time through the modifications and enhancements of it existing physical IT resources. Rapid changes and evolutions in technology standards will drive an HRO to invest in newer physical IT resources because as Moore's Law points out the ratio of the performance of a microprocessor to its cost doubles every eighteen months.

Empirical evidence of this relationship is provided by Brynjolfsson and Kemerer (1996) who show that software vendors frequently update their software products with new levels of functionality. Otherwise the firm's products will quickly become obsolete.

Second, the dynamic capabilities perspective also provides insight into how the growth of an HRO's physical IT resources can enable it to achieve greater levels of agility and flexibility to improve its safety performance. High reliability organizations require access to the latest physical IT resources (Grabowski and Roberts 1999). With access to the latest physical IT resources, HROs will become extremely flexible and thus have the ability to "grow, expand, contract, and respond to changes in a dynamic, high-tempo environment." In the U.S. Motor Carrier Industry, an HRO's underlying physical IT resources and growth in physical IT resources can enable it to rapidly respond to situations such as sudden changes in the driver's medical condition. For example, the Federal Motor Carrier Safety Administration (FMCSA) is studying how fatigue management technology can enable the vehicle's dispatch center to monitor the medical conditions of the driver in real-time. Fatigue management technology consists of electro-optical systems and sensors that monitor both the driver's eye movement and heart-beat to measure the driver's ability to perform on-the-job driving functions (U.S. Department of Transportation 2005a).

Therefore, by continually enhancing its underlying physical IT resources with state-of-the-art technologies, an HRO can increase its capability to respond to situations that may have previously contributed to poor safety performance.

Third, the dynamic capabilities perspective also suggests that the development of flexible physical IT resources is a long-term endeavor (Harris and Katz 1991). It takes an HRO a tremendous amount of time to establish and create linkages between the multiple components that constitute an IT system. Additionally, these linkages need to be maintained and enhanced over time to prevent failure of the IT system (Mata et al 1995; Subramani 2004). In fact, as pointed out by Weill and Broadbent (2002) and Bharadwaj (2000), it takes between 5 to 7 years to reap the benefits of physical IT resources that has become stabilized and well integrated into an organization. Gurbaxani and Mendelson (1990) empirically show that the firm's IT spending budget exponentially grows over time which in part illustrates top management's commitment to its investment in its physical IT resources. Lastly, Forman (2005) hypothesizes out that prior investments in physical IT resources should increase the net benefit of adopting new physical IT resources.

An HRO's growth of its physical IT resources can play a prominent role in improving its safety performance. The HRO's physical IT resource takes time to develop and coalesce.

Therefore, as an HRO's physical IT resources grows over time, theorganization will develop physical IT resources that is more agile and flexible and hence provide it with better safety performance. These arguments lead to the following hypothesis:

H2: The greater the increase in physical information technology resources the better the firm's safety performance.

Human IT Resources and the Firm's Safety Performance

The next tangible IT resource is an HRO's human IT resources. Viewed from the RBV, human IT resources are critically important because it is the highly skilled and adaptable IT personnel that enable an HRO to use, exploit, manage and benefit from its physical IT resources (Kayworth et al 2001; Byrd and Turner 2001; Ang and Slaughter 2000; and Agarwal and Sambamurthy 2002). Further, it is the intellectual IT resources that act as the "mortar" that binds the physical IT resources into robust and functional IT services (Weill et al (2002). In a business case study, Weill et al (2002) suggest thatthe human IT resource provides t he policies, architectures, planning, design, construction, and operations necessary for viable physical IT resources. It is the human IT resource which enables an HRO to effectively mobilize appropriate physical IT resources for the purposes of sensing-and-responding to changes in the external environment. As Bharadwaj (2000) points out, it is the technical IT personnel's unique skills in areas such as programming, systems analysis and design, and competencies in emerging technologies that enables the organization to use and exploit the firm's physical IT resources (Jarvenpaa and Ives 1991).

Human IT resources play an instrumental role in improving an HRO's safety performance. Human IT resources are responsible for configuring and programming complex physical IT resources to alert the HRO of potentially involvement in unsafe situations. In a recent example, Cavusoglu, Mishra, and Raghunathan (2005) describe how IT personnel were responsible for designing and implementing complex physical IT resources to achieve better firm performance. Increasingly, physical IT resources are being used for the purposes of monitoring and alerting the firm to situations where its employees or other intruders are attempting to gain access to unauthorized data or information from its computer systems (Cavusoglu et al 2005). Especially in HRO settings, human IT resources are responsible for implementing complex and flexible IT systems such as fatigue management technologies and vision enhancement systems to monitor and analyze the behavior of the firm's employees and physical assets to prevent unsafe situations from arising (Hubbard 2003; Crowston 2003). Therefore, these examples illustrate how it is the skills of the IT personnel which in part enable an HRO to derive benefits from IT-enabled safety resources.

Second, human IT resources can increase an HRO's absorptive capacity (Cohen and Levinthal 1990; Fichman 2001; Sambamurthy et al 2003) to make better workplace safety decisions which leads to improved safety performance. An HRO's absorptive capacity can be increased through the implementation of physical IT resources, such as virtual organizational technology (VRO).

Human IT technical personnel implement VRO technology to facilitate flexible decision making which is critically important for managing HRO personnel that are not located in the same physical location (Grabowski and Roberts 1999). To support flexible decision making practices, human IT resources can create a computer mediated communication (CMC) environment thatoffer s HRO employees the opportunity to challenge assumptions, identify errors, voice issues, and reinforce virtual norms. Using the CMC environment, HRO employees may take a proactive approach for initiating concerns about how the firm's safety climate using the firm's physical IT resources as a channel to voice concerns. Second, human IT resources may proactively build systems that are used to monitor employees in terms of the workplace safety actions that may place the HRO in danger. Indeed, in many HRO workplace settings, physical IT resources are being implemented to monitor the labor practices of HRO employees to prevent them from violating rules and regulations. The benefits of physical IT resources has also received insight through the work of Rogers (1983), Milgrom and Roberts (1992) and Pinnsenaut and Kraemer (1997). These researchers show that by implementing physical IT resources, an HRO's human IT resources can facilitate organizational performance improvement. These arguments lead to the following hypothesis:

H3: The greater the investment in human information technology resources the better the firm's safety performance.

Growth in Human IT Resources and the Firm's Safety Performance

The fourth tangible IT resource is the growth in an HRO's human IT resources. From a dynamic capabilities perspective (DCP), it is the episodic renewal of an HRO's human resources thatcan enable thes e organizations to address issues of technological change (Teece et al 1997). Through the growth of its human IT resources, an HRO will have access to the latest technical skills that will enable it to rapidly respond to changes in both its internal organization and the external environment. Employing IT personnel with knowledge of the latest physical IT resources is very important especially as these technologies are relatively new to the market. Further, by hiring IT personnel from its competitors, the HRO can gain insight into how these physical IT resources are being used across an industry to improve their safety performance.

The dynamic capabilities perspective also points out that the development of human IT resources typically evolves over a long period of time (Bharadwaj 2000; and Harris and Katz 1991). The team-oriented nature of IT human resources is dependent on interpersonal relationships which can be organizational specific (Sambamurthy and Zmud 1997). Bharadwaj (2000) describes in her framework that a firm develops higher levels of human IT competency when new employees are added to the organization.

Specifically, Bharadwaj (2000) points out that “when new employees are added to the firm they are not only trained in software systems but also in the development methodologies unique to the firm. Thus there are increasing returns to the firm as they add qualified professionals to an existing network of programmers.” A similar finding is also described in Dierickx and Cool (1989) who suggest that the firm suffers a slower decay rate of team-embodied knowledge as this tacit knowledge is passed onto future generations of IT knowledge workers within the firm

An HRO’s growth in its human IT resources can play a prominent role in improving its safety performance. Over time, an HRO’s human IT resources will become more competent because the organization’s human IT personnel will have developed closer relationships with its safety managers thus improving the responsiveness of the IT department to thesafety needs of the organization. Therefore, an HRO with more agile and competent personnel can provide the firm with better safety performance. These arguments lead to the following hypothesis.

H4: The greater the increase in investment of human information technology resources the better the firm’ssafety performance.

Research Method

Sample

This model is tested with an original data set drawn from the U.S. Motor Carrier Industry. The benefits of examining a single industry have been documented in numerous studies, for example Hess and Kemerer (1994), Duliba et al. (2001), and Chiasson and Davidson (2005). Using data across multiple industries might introduce substantial variation in safety performance characteristics from extraneous factors, such as differing technological characteristics or the extent to which the firm operates in unsafe situations. In addition, firms in different industries may experience sharply varying degrees of government regulation which can affect their investment in safety resources. By examining a single industry, we can control for these exogenous factors, allowing a cleaner test of the theory. A single industry study also makes greater comparability possible in the operationalization of variables across the sample.

As described in the introduction of this chapter, the U.S. Motor Carrier Industry was selected for this study primarily because of the importance of IT investment and the need to operate error-free by the firms in this industry. As in other high reliability organizational settings, while the actual involvement in unsafe incidents might be low in this industry, the risk of small failures amplifying into actual unsafe situations can be high (Vogus and Welbourne 2003).

Moreover, motor carrier firms are motivated to operate error-free because they are constantly under public scrutiny to improve their safety performance (Corsi and Fanara 1988). Thus, improving the firm's safety performance is critical to success in this industry.

Measurement of Variables

Firm safety performance is measured by the number of crashes that the firm was involved in. Previous studies have also measured firm safety performance by the number of crashes (Michener and Tighe 1992; Rose 1990; Keeler 1994; Daicoff 1988; and Rose 1990). Each firm's IT investment is measured in 2002 and 2003 and total number of crashes it was involved in between January 2002 and February 2004.

The data source for this study is the U.S. Department of Transportation's Federal Motor Carrier Safety Administration (FMCSA) SafeStat database. This time window affords an accurate measure of a firm's safety performance because of the length of time necessary to implement and realize benefits from the firm's information technology activities. To operationalize the IT infrastructure variables, detailed firm data is drawn from Harte-Hanks, Inc.'s Computer Intelligence (CI) database. The database is derived from extensive surveys of companies' IT capabilities. The CI data has been used in a number of prior studies, for example, Brynjolfsson and Hitt (1996), Hitt (1999), and Zhu and Kraemer (2002).

As Hitt (1999, p. 139) argues, "Then we can use CI computer capital stock measure as a good indicator of overall firm IT." We adopt the CI data as a proxy for a firm's investment in physical and human IT resources.

The specific measure of physical IT resources is the total number of PCs in the firm divided by the number of employees in the firm. This measurement is consistent with previous studies that attempt to measure the physical IT investment level or intensity of IT (Breshnahan et al. 2002; Zhu and Kraemer 2002). Thus, the measurement of physical IT resources (PHYSICAL-IT) can be an accurate gauge of the relative intensity of physical IT resources among firms. The firm's growth in physical IT resources (PHYSICAL-IT-GROWTH) is operationalized as the firm's physical IT resources in 2003 subtracted from its physical IT resources in 2002.

The firm's human IT resources (HUMAN-IT) is operationalized as the number of programmers. As Bharadwaj (2000) points out, it is the technical IT personnel's unique skills in areas as programming that provides a proxy of a firm's human IT resources. The firm's growth in its human IT resources (HUMAN-IT-GROWTH) is operationalized as its human IT resources in 2003 subtracted from its human IT resources in 2002.

Other independent variables have been cited as influencing the safety performance of motor carrier firms and we control for them in our model. Our first control variable is the number of power-units in 2004 (POWERU) in the organization which is a common measure of firm size in transportation studies (Christiansen et al 2004; and Mejza and Corsi 1999). Power-units is the total trucks, tractors, and hazardous material tank trucks. Our next control variable is the rate of state-wide accidents in 2004 (STATE-ACCIDENTS). State wide accidents is measured as the average accident rate of firms headquartered in each state in our sample. The quality of the non-IT resources in the firm is measured by driver and vehicle safety rating measures in 2004. Quality of non-IT capital is measured by the VEHICLE safety rating which reflects the firm's total number of vehicle violations normalized by power-units (Mejza and Corsi 1999; Mejza et al 2003). Quality of non-IT human resources is measured by the DRIVER safety rating which reflects the firm's total number driver violations normalized by power units (Mejza and Corsi 1999; Mejza et al 2003). To address potential endogenous issues a firm's previous crash performance (CRASH-2003) is included in the model. Table 1 presents the variables along with descriptive statistics.

Table 1: Descriptive Statistics

Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Dependent Variable					
CRASHES-2004	517	32.717	138.435	0	2111
Independent Variables					
PHYSICAL-IT	517	.239	.237	.001	1.406
HUMAN-IT	491	.166	.375	0	2.397
PHYSICAL-IT-GROW	516	.015	.143	-.700	1.217
HUMAN-IT-GROW	491	.005	.153	-.693	.693
Control Variables					
POWER-UNITS	517	4.539	1.442	.693	9.711
STATE-WIDE-ACCIDENTS	517	3.493	.535	0	4.211
DRIVER	489	3.516	1.159	0	4.615
VEHICLE	482	3.581	0.767	0	4.599
CRASHES-2003	517	30.617	125.299	0	1859

Model

A Poisson regression is used to test the model. Wooldridge (2003), Vogus and Welbourne (2003), Gittelman and Kogut (2003), Henderson and Cockburn (1994), Jensen (1987), and Shane (2001; 2002) specifically note that Poisson regression is an appropriate methodology where the dependent variable consists of non-negative count data. As pointed out by Michener and Tighe (1992), the Poisson method has a long history of use in crash studies including Rose (1990) and Keeler (1994). For example, Noronha and Singal (2004) did one such study, using a Poisson regression to analyze airline mishap incidents as the dependent variable of interest.

The benefit of this approach, Shane (2001) points out, is that a Poisson regression "is designed for maximum likelihood of the number of nonnegative counts of events." Further, in this Poisson model specification, we created a log-linear functional form to address skewness among most of our independent variables (Haunschild and Rhee 2004).

Results

Our analysis begins with an examination of the correlation matrix as shown in Table 2. The independent variables do not show statistically significant correlation above the .70 threshold (Zhu and Kraemer 2002), which indicates that these variables are distinct. Given these results, we likely conclude that we can proceed with our model without much concern for multicollinearity.

Table 2: Correlation Matrix

	CRASH-2004	PHYSICAL-IT	PHYSICAL-IT-GROWTH	HUMAN-IT	HUMAN-IT-GROWTH	POWER-UNITS	CRASH-2003	STATE-ACCIDENTS	DRIVER	VEHICLE
CRASH-2004	1									
PHYSICAL-IT	-0.0950 * (0.0307)	1								
PHYSICAL-IT-GROWTH	0.0736 + (0.0950)	- 0.2150 ** (0.0000)	1							
HUMAN-IT	0.3596 ** (0.0000)	0.1611 ** (0.0003)	0.0248 (0.5830)	1						
HUMAN-IT-GROWTH	0.1531 ** (0.0007)	- 0.0095 (0.8342)	0.1315 ** (0.0035)	-0.1865 ** (0.0000)	1					
POWER-UNITS	0.4725 ** (.0000)	-0.1905 ** (0.0000)	0.0668 (0.1294)	0.3466 ** (0.0000)	0.0318 (0.4819)	1				
CRASH-2003	0.9987 ** (0.0000)	- 0.0979 * (0.0260)	0.0748 + (0.0895)	0.3643 ** (0.0000)	0.1533 ** (0.0007)	0.4849 ** (0.0000)	1			
STATE-ACCIDENTS	0.1284 ** (.0034)	-0.1393 ** (0.0015)	- 0.0079 (0.8576)	0.0180 (0.6902)	-0.0001 (0.9975)	0.1560 ** (0.0004)	0.1288 ** (0.0033)	1		
DRIVER	0.0632 (0.1627)	0.0123 (0.7856)	0.0253 (0.5769)	0.0810 + (0.0812)	-0.0031 (0.9465)	0.1973 ** (0.0000)	0.0632 (0.1627)	0.2013 ** (0.0000)	1	
VEHICLE	0.0117 (0.7983)	0.0059 (0.8972)	0.0279 (0.5416)	0.0723 (0.1227)	-0.0190 (0.6857)	0.0684 (0.1336)	0.0144 (0.8029)	0.1043 * (0.0220)	-0.0140 (0.7597)	1

** $p < .01$, * $p < .05$, + $p < .10$

Correlation among the main model independent variables is shown in the shaded region of the table.

Specifically, this model includes four hypotheses (Hypotheses 1, 2, 3, and 4). The firm's safety performance is measured by the number of crashes in 2004 (CRASHES-2004) is our dependent variable. The independent variables include physical IT resources (PHYSICAL-IT), human IT resources (HUMAN-IT), physicalIT resources growth (PHYSICAL-IT-GROWTH), and human IT resource growth (HUMAN-IT-GROWTH). The model is shown in the following equation.

$$\text{CRASHES-2004} = \beta_0 + \beta_1\text{PHYSICAL-IT} + \beta_2\text{HUMAN-IT} + \beta_3\text{PHYSICAL-IT-GROWTH} + \beta_4\text{HUMAN-IT-GROWTH} + \gamma_1\text{POWER-UNITS} + \gamma_2\text{STATE-ACCIDENTS} + \gamma_4\text{ DRIVER} + \gamma_5\text{ VEHICLE} + \gamma_6\text{ CRASHES-2003}$$

Table 3 presents the results from the Poisson regression model. Hypothesis 1, that the greater the physical IT resources the better the firm's safety performance, is strongly supported. The coefficient for physical IT resources (PHYSICAL-IT) is negative and statistically significant at the 0.01 level. Similarly, H2, that the greater the increase in physical IT resources (PHYSICAL-IT-GROWTH) the better the firm's safety performance, is also strongly supported at the 0.01 level.

Hypothesis 3, the greater the investment in human information technology resources (HUMAN-IT) the better the firm's safety performance, is strongly supported at the 0.01 level.

Similarly, Hypothesis 4, that the greater the increase in human IT resources (HUMAN-IT-GROWTH) the better the firm's safety performance, is also supported at the 0.05 level. Lastly, in terms of the control variables, all of the control variables are positive and statistically significant. Consistent with our expectation, the larger the firm (POWER-UNITS), the greater the likelihood that the firm is involved in crashes. Additionally, firms that operate in states that experience a greater rate of accidents (STATE-ACCIDENTS) lead to poor firm safety performance. Firms that have poorly performing vehicles (VEHICLE), experience poor safety performance. Similarly, firms that employ drivers who experience violations (DRIVER) experience poor safety performance. Lastly, firms that experience crashes in 2003 (CRASH-2003) experience crashes in 2004.

Table 3: Model Results

Independent Variables	Model Estimated Coefficients	Standard Errors
PHYSICAL-IT (log)	-.3096 **	(.060)
HUMAN-IT (log)	-.0671 **	(.023)
PHYSICAL-IT-GROW (log)	-1.1145 **	(.100)
HUMAN-IT-GROW (log)	-.1739 *	(.074)
POWERU (log)	.7984 **	(.017)
DRIVER (log)	.1760 **	(.019)
VEHICLE (log)	.0734 **	(.024)
STATE-ACCIDENT (log)	.3403 **	(.030)
CRASH-2003	.0055 **	(.000)
CONSTANT	-3.490 **	(.169)
N	457	
R^2	0.7702	

** $p < .01$, * $p < .05$, + $p < .10$

Discussion

We have drawn on the resource-based view to build a theory linking IT investment to the firm safety performance in the context of high reliability organizations. The resource-based view provides us a strong foundation to posit why an HRO's specific IT resources contribute to safety performance. In combination with the dynamic capabilities theory, the resource-based view points to how the constant renewal and reconfiguration of an HRO's IT resources is a critical dimension of improving safety performance. Our model extends the work of Bharadwaj (2000) whose insight on a firm's IT resources as a critical component of firm performance has provided an important building block for our theory.

To the best of our knowledge, this is the first empirical study examining IT investment in the context of high reliability organizations. Previous information systems literature has examined safety resources as an explanatory variable for increased IT use. Further, it appears that IT investment does lead to improvement in an HRO safety performance because an HRO's IT resources: 1) provide an environment to facilitate the building of safety technologies, 2) increase the absorptive capacity of the HRO to learn of and solve safety problems; and 3) enable for greater levels of coordination and collaboration within an HRO's firm boundaries. Our results are consistent with the resource-based view which argues that a firm's resources are essential to improving firm performance in the marketplace.

These results are also consistent with the theoretical work of Bharadwaj (2000), who argued that IT investment increases firm performance through a building of long-term performance improvements. Our findings complement and contribute to the stream of information systems literature examining the impact of IT investment on firm productivity and performance.

The present study provides significant contributions to the literature, but it does have several limitations. First, one must always exercise caution in generalizing from a study based on a single industry. We do note, however, that the variables used in the study — physical IT resources, human IT resources, and growth of IT investment resources — are of course not unique to the U.S. Motor Carrier Industry.
Future research should extend this study by examining these variables in other industries, which would aid in establishing generalizability and would also likely uncover interesting differences between industries. One possible context to examine the role of IT and safety performance would be in industries that experience rapid changes in product lifecycles. Lower-level employees in high velocity industries rely on the IT resources to make quick and rapid decisions. Therefore, by studying the role of IT in terms of increased agility to respond to dynamic market changes, the findings of this study may become even more generalizeable. Second, future research might also examine the alignment of the IT function with the top management of the firm. Specifically, a research study that examines the degree of alignment between the IT strategy and corporate safety strategy might provide some insight in terms of the variation of firm performance across organizations.

Organizations that have greater alignment in terms of its core IT functions and corporate safety strategy might have greater firm financial performance as well as safety performance.

Conclusion

This chapter, grounded in resourced-based view, has linked IT investment to improve safety performance in the context of high reliability organizations. We have built a model positing that investment in information technology will likely lead to improved safety performance. We have also provided theoretical arguments in the context of high reliability organizations as to why an HRO's IT resources improve safety. Empirical evidence based on the U.S. Motor Carrier Industry largely supports our model. In conducting this research we have shed light on the nexus between IT and safety performance. We hoped that this study will generate further investigation on this interesting and important topic.

Chapter 3: Technology Adoption Patterns in the U.S. Motor Carrier Industry

Introduction

At approximately 2:45 pm on January 13, 2004 in Baltimore, Maryland, a fuel-tank truck was traveling at excess speeds on an overpass of Interstate 695. When the fuel tank driver lost control of his vehicle, it plunged into a concrete bridge rail and then rolled over the rail onto Interstate 95, the highway underneath the overpass. As the truck came to rest on Interstate 95, oncoming traffic collided with it, and it subsequently burst into a ball of flames (Buck et al 2004). This incident had many devastating implications. First, there were a total of four fatalities, each of which entailed a high personal and societal cost. Second, the crash caused immediate impacts to the fuel tank company in terms of lost revenues for the undelivered load and loss of the equipment involved. In addition, the company faced a series of lawsuits from relatives of the deceased and a bill for the environmental clean-up necessitated by the vehicle crash and subsequent damage. In a highly competitive industry with narrow profit margins, losses of this magnitude could threaten a firm's ability to continue as a growing concern. As a result, firms within this industry recognize the importance of initiating management practices that will minimize the number and severity of their crashes. Third, there are numerous supply chain implications of severe crashes like the one under discussion. For example, on Interstate 95, there are over 200,000 vehicles that travel between Baltimore, Maryland and Washington, D.C. on a given day (Buck et al 2004).

When a catastrophe such as the one just described occurs, many firms are impacted in terms of their ability to route products and services to their customers. In the above situation, it took authorities approximately 12 hours to return the I-95 and I-695 corridor back to normal. As a result, supply chain services were directly and adversely impacted. The National Highway Traffic Safety Administration estimates $230 billion in lost economic value because of the 400,000 vehicle crashes that occurred in 2002 (NHTSA 2006). In addition to the obvious tragic loss of life, which all too often accompanies motor carrier crashes, there is the important issue of efficiency in the supply chain. From the carrier's perspective, there are significant direct costs associated with motor carrier accidents (Weber and Weber, 2004). Poor safety performance also has negative consequences in terms of higher insurance costs, financial liabilities to the victims of the accidents, and loss of corporate goodwill. (Corsi, Fanara, and Jarrell 1988).

In the aftermath of motor carrier deregulation, in particular, the 1980 Motor Carrier Act, a steady stream of research has investigated the relationship between deregulation and motor carrier safety (Corsi, Fanara, and Jarrell 1988; Corsi and Fanara 1988; and Kraas 1993). In addition, a body of recent research has explored various factors which might contribute to motor carrier safety performance. Studies by the federal government have examined both the role of government vehicle inspection programs on motor carrier safety as well as the impact of driver training programs and strategies on overall carrier safety performance.

Mejza and Corsi (1999) and Mejza, Barnard, Corsi and Keane (2003) provide evidence on the role of a range of motor carrier management practices in enhancing carrier safety performance. Crum and Morrow (2002) developed a model of truck driver fatigue and studied the impact of carrier scheduling practices on fatigue as part of an overall effort to link greater driver fatigue with a higher likelihood of crashes.

One important way to enhance the firm's safety performance, which has received relatively little attention in the motor carrier literature, is an investment in safety management technologies. Safety management technology is defined as physical IT resources that may be used to monitor and alert the firm to uncertainty in the external and internal operating environment. Examples of safety management technology in the trucking industry include on-board computers, anti-rollover technologies, and collision-avoidance devices. Safety management technologies may be used to improve the firm's safety performance. Safety management technologies can be applied to several different application areas including: managing the maintenance and use of the firm's physical equipment, monitoring employee behavior, and improving safety management decisions. Safety management technologies may also be used to facilitate increased information accuracy, visibility, and accessibility. Increased information accuracy, visibility, and accessibly can enable the firm's safety managers to become aware in real time or near real time of operational metrics and the status reports of a firm's equipment and personnel.

Therefore, if the firm's equipment and personnel are in danger of performing below acceptable safety limits, the firm's managers can quickly become aware of these undesirable behaviors. Another key way to improve firm safety performance is through the enablement of alerts for out-of-control conditions. Any time deviations in the firm's safety performance occur, alerts can enable the firm to take rapid corrective action. Therefore, through both increased information sharing and alerts, the firm may be able to proactively take appropriate action to improve the firm's safety performance. In sum, there are many potential benefits that can be derived from safety management technologies.

Although there has not yet been a comprehensive study of motor carrier safety technology, research to date has studied various aspects of motor carrier technology. Manrodt, Kent, and Parker (2003) provided survey evidence regarding motor carrier implementation of mobile communications technology. Rishel, Scott, and Stenger (2003) studied the use of satellite communication systems in the U.S. Motor Carrier industry. Hubbard (2003) focused specifically on on-board computers and their role in enhancing motor carrier productivity. Giaglis, Minis, Tatarakis, and Zeimpekis (2004) examined vehicle routing technologies and their role in distribution management.

This chapter contributes to the literature on motor carrier safety by providing results of a comprehensive survey of safety technology adoption in the U.S. Motor Carrier industry.

With the assistance of the Federal Motor Carrier Safety Administration within the United States Department of Transportation, survey responses were obtained from more than 400 carriers across the country. This chapter proceeds in the following section with details on the survey methodology. The main body of this chapter reports adoption rates of safety technologies dealing with five different operational categories: driver communication, vehicle communication, driver performance, vehicle performance, and vehicle maintenance. In a subsequent section, this chapter examines the linkage between technology adoption and firm characteristics, including size, geographic scope, and load type.

Methodology

Research Context

The empirical context for this study is the U.S. Motor Carrier industry. Specifically, this research setting focuses on trucking companies and their adoption of safety information technologies. The specific unit of analysis for the study is the motor carrier firm and its safety technology adoption pattern.

Two main criteria were identified in selecting this empirical context. First, all of the main safety adoption technologies needed to be present in the research setting, although the adoption rates for each of the technologies could vary widely across the firms in the research setting. Second, the setting selected required that firms make significant and ongoing implementation efforts for each of the adopted technologies in contrast to just acquiring safety information technology solutions. Third, a single industry was required to solve concerns about exogenous factors.

Further, the U.S. Motor Carrier industry was selected for this study primarily because of the importance of safety technology adoption to the firms in this industry, across a wide range of technologies and carrier operations. Trucking firms, constantly under public scrutiny to identify new ways to manage safety (Corsi and Fanara 1988), increasingly recognize that safety technologies offer concrete safety performance improvement possibilities. Lastly, the reader is referred to Chapter 2 which discusses the benefits of examining a single industry.

Questionnaire Development

To develop the questionnaire, academic, government and industry professionals who are experts in the area of safety technology management were interviewed. Additionally, a review of the government, academic, and industry safety technology adoption literature was conducted to identify relevant safety management technologies. In total, more than 120 hours were spent on identifying truck safety management technologies. On the basis of the interviews and a review of the safety management literature, a preliminary version of the respondent-friendly questionnaire was developed (Dillman 2000, p. 150). When it was possible, existing items were used.

The questionnaire was also pre-tested to verify the appropriateness of the terminology, the clarity of the instructions, and the response formats. The questionnaire was distributed to a sample of seven Vice Presidents of Safety. Five questionnaires were returned. Respondents indicated that some of the questions were ambiguous. These questions were reworded to resolve any issue of ambiguity.

Furthermore, the “think-aloud” cognitive interview pre-testing technique as recommended by Dillman (2000, p.42) and Tourangeau et al (2000, p. 326) were used to help resolve any additional potential problems with the questionnaire. Lastly, telephone interviews were conducted ex-post to verify the relevance and clarity of the survey questions (Tourangeau et al 2000, p. 294).

The questionnaire contains a list of items tapping the safety technology adoption construct. The questionnaire asked respondents to indicate what percentage of their drivers or vehicles have or use any of the pre-identified safety technologies. These items are objective questions. As pointed out by Tourangeau et al (2000), respondents will be providing an estimate to these items because informants rely on their memory strategy to recall this information. Moreover, as pointed out Tourangeau et al (2000), the estimate that respondents provide will be a function of the item’s familiarity to the respondent. Therefore, to improve the level of estimation, definitions were provided beneath each of the safety technology items (see the Appendix). The definition to these items (otherwise known as “retrieval cues,” see Tourangeau et al 2000, p. 96) facilitates the respondent’s ability to recall the firm’s frequency of use of the item. Through both the pre-testing and cognitive interviews, none of the respondents indicated any difficulty comprehending the directions or reference points in this survey (Tourangeau et al 2000, p. 45).

Moreover, based upon the review of the pre-test responses, some items received a zero response score. As Tourangeau et al (2000) point out "when an item seems unfamiliar or inaccessible enough, respondents judge that they never saw it before" and, as a result, provide zero level scores.

To increase the respondent's ability to retrieve information about their level of safety technology adoption, similar items were grouped together so that each set of questions was on a related topic. As pointed out by Tourangeu et al (2000), these researchers showed that "answering one question about an issue made respondents able to answer a related second question more quickly." Therefore, the grouping of similar items together reduces the cognitive burden of the respondent and potentially mitigates any problems of item-level non-response. Through both the pre-testing and cognitive interview process, respondents did not indicate any problems understanding the survey.

Sampling Frame

The mail survey was distributed on behalf of a sponsoring organization (Federal Motor Carrier Safety Administration (FMCSA)). The use of a sponsoring organization can increase the legitimacy of the survey research project (Tourangeau et. al 2000, p. 307). The initial sampling frame consisted of the largest trucking companies in the fifty United States and the District of Columbia. The study targets the largest motor carrier companies, because it is these firms that may have the financial resources to adopt safety technologies.

Key Informant

It is important that the respondents are competent and knowledgeable to report on the key constructs of interest in the research model (Bagozzi, Yi, and Phillips 1991). It is also important to minimize the effects that differences in respondent knowledge, position, and perceptions have on responses by using specific measures to asses the respondent's competency and knowledge of the phenomena of interest (Jap 1999). To address these issues, the sponsoring organization was asked to identify key informants who would have the best ability to respond to the items in the questionnaire. The sponsoring organization identified the Vice President of Safety and Director of Safety as the most competent individuals in an organization to respond to the phenomena of interest. Therefore, the key informant for this study was either the Vice President or Director of Safety.

The FMCSA state directors contacted by telephone the Vice President or Director of Safety of the largest motor carrier companies in forty-seven of the United States to request participation in this study. As described by Dillman (2000, p. 156), the pre-notification process improves response rates to mail surveys. Moreover, survey respondents were motivated to participate in this project because this is viewed as a part of its federal government regulatory compliance activities.

To further motivate the respondents to participate in this project, the mail survey package contained a cover letter, questionnaire, and a pre-addressed, pre-postage paid return envelope (Dillman 2000; and Tourengeau et al 2000).

Specifically, the cover letter was personalized as a means to appeal for help from the respondent to participate in this project. For example, the cover letter included information that the research study was being co-sponsored by the FMCSA and a large public university in one of the Mid-Atlantic States. The cover letter also provided assurances of confidentiality of informant responses as permitted to the extent possible by the law as a means to increase the respondent's willingness to complete the questionnaire (Tourangeau et al 2000, p. 261). As a token of appreciation for participating in the research project (Dillman 2000, p. 162), the cover letter offered each firm an executive summary and presentation of the results in return for completing the survey. As recommended by Dillman (2000, p. 162), each letter was personally signed to help increase the response rate to questionnaires.

Nonresponse bias was assessed using analysis of variance techniques. Considering the second half of respondents as most likely to be similar to nonrespondents, a comparison of the first and second group of respondents provides a test of response bias in the sample (Armstrong and Overton 1977). These two groups of respondents were compared on firm size (sales). The analysis of variance test did not indicate any response bias on this firm size dimension ($p > .10$). Thus, a likely conclusion is that nonresponse bias is not found in the sample.

After the initial mailing, several follow-up attempts were made to contact the key informant (Dillman 2000). A total of one-thousand twenty-five surveys were distributed. Fourteen surveys were undeliverable.

One hundred ninety respondents formally declined to participate in the survey. Some of the reasons provided by the respondents for formally declining to participate include: it is company policy to not participate in surveys (26.84%), the firm's focus of operations is in the leasing of trucks (1.58%), the firm was involved in a reorganization (4.74%), the survey was lost in the organization (3.16%), the key informant did not have time to work on the survey (18.42%), the key informant's family member was sick and therefore the key informant couldn't devote resources to the survey (1.58%), the key informant was unreachable (17.89%), the key informant did not want to participate because of an undisclosed reason (2.63%), the survey was not applicable to the firm's business operations (7.37%), or the key informant was not the appropriate person for the survey (15.79%). Therefore, the effective sample size was eight-hundred twenty-one. Four-hundred fifteen surveys were returned for an effective total response rate of 50.55 percent (415/821).

Results of the Empirical Analysis

The analysis begins by examining the five main safety technology adoption categories identified in the survey: driver communication technologies, vehicle communication technologies, driver performance and driver assistance/regulation technologies, vehicle performance and monitoring technologies, and vehicle maintenance technologies. Each respondent was asked to indicate the percent that their firm has or uses each safety technology within each of the five technology categories. The survey contained a total of twenty six items across these five technology categories.

Driver Communication Technologies

Driver communication technologies are defined as a type of safety technology that enables the driver to communicate with the firm's dispatching center in real-time. Table 4 provides a list and description of the survey items that were used to measure driver communication technologies. Driver communication technologies consist of cellular telephones, computers with satellite connections, computers with wireless capabilities, handheld personal digital computers (PDAs) with wireless capabilities, and mayday systems. Firms that adopt these safety technologies may benefit from the real-time communication capabilities that these systems provide to both the firm and its employees. For example, through the use of a mayday system, a truck driver can initiate a real-time request for emergency roadside assistance. A mayday system can consist of a hidden panic button that alerts a 24 x 7 response center of an extremely urgent problem that requires emergency assistance (Consumer Guide 2006).

Table 4: Driver Communication Technologies

Safety Technology	Notes
Cellular telephones (with or without hands-free headsets)	(U.S. Department of Transportation 1999)
Computers with satellite connections (always on)	(U.S. Department of Transportation 1999)
Computers with wireless capabilities	(U.S. Department of Transportation 1999)
Handheld personal digital computers (PDAs) with wireless capabilities	(U.S. Department of Transportation 1999)
Mayday systems	A mayday system alerts the truck's dispatcher that the driver was involved in a crash and provides details of the incident. It may be initiated manually by the driver or automatically through the use of vehicle sensors. (Consumer Guide 2006)

The results demonstrate that many firms have adopted driver communication technologies. Table 5 provides a description of the results of the survey results. For firms that adopted safety technologies (percent greater than 0% adoption), there are several driver communication technologies that have been fully adopted (in use by all of the firm's drivers), including mayday systems (59.37%), computers with satellite connections (34.81%), and cellular telephones (28.42%). Moreover, over 93% of the firms in the sample have adopted cellular telephones with or without hands-free headsets for at least some of their drivers.

Table 5: Results - Driver Communication Technologies

			0.001% - 5.00%	5.01% – 25%	25.01% - 50.0%	50.01% - 75%	75.1% - 99%	100%
Safety Technology	**% > 0% Adoption**	**Mean > 0% Adoption**	**Minimal Adoption**	**Partial Adoption**	**Moderate Adoption**	**Above Average Adoption**	**Substantial Adoption**	**Full Adoption**
Cellular telephones (with or without hands-free headsets)	93.83%	79.06%	2.11%	4.47%	11.58%	15.79%	37.63%	28.42%
Computers with satellite connections (always on)	34.51%	58.85%	16.30%	16.29%	14.08%	4.44%	14.08%	34.81%
Computers with wireless capabilities	32.22%	20.06%	39.84%	42.27%	6.51%	2.44%	3.25%	5.69%
Handheld personal digital computers (PDAs) with wireless capabilities	27.60%	13.71%	61.54%	27.88%	1.93%	1.92%	1.92%	4.81%
Mayday systems	16.84%	75.77%	14.06%	3.13%	6.25%	1.56%	15.63%	59.37%

Vehicle Communication Technologies

Vehicle communication technologies are defined as a type of safety technology that is installed on the truck. These technologies are configured to automatically detect and provide the driver with real-time geographic and/or physical proximity information.

Table 6 provides the list of survey items that were used to measure vehicle communication technologies. Vehicle communication technologies consist of GPS systems, automatic collision notification systems, and automatic vehicle identification (AVI) systems. These safety technologies may provide the firm with many benefits, including the real-time location of the firm's physical vehicle assets. For example, through the use of automatic vehicle identification (AVI) systems, regulators can collect compliance review enforcement information at mainline speeds without requiring roadside inspections of the truck.

Table 6: Vehicle Communication Technologies

Safety Technology	Notes
GPS systems	GPS systems use satellite technology to provide for automatic detection of the vehicle's real-time location. (U.S. Department of Transportation 2003; and Mactrucks 2006)
Automatic collision notification (ACN) systems	ACN systems automatically detect and send crash information instantly to a public safety answering point or to the vehicle's dispatcher. (National Transportation Safety Board 1999)
Automatic vehicle identification (AVI) system	AVI's are dedicated short-range radio communication systems. These systems consist of a transponder or RF tag on the vehicle and a stationary reader system. (U.S. Department of Transportation 1999)

The survey results provide evidence that that some firms have adopted vehicle communication technologies. Table 7 provides a description of the survey results. For firms that have adopted safety technologies, there are several vehicle communication technologies that have been fully adopted (in use by all vehicles in a firm's fleet) including GPS systems (38.07%) and automatic vehicle identification (AVI) systems (39.47%). Interestingly, over 53% of firms have adopted GPS systems in at least some of their vehicles.

Table 7: Results– Vehicle Communication Technologies

Safety Technology	% > 0% Adoption	Mean > 0% Adoption	0.001% - 5.00% Minimal Adoption	5.01% – 25% Partial Adoption	25.01% - 50.0% Moderate Adoption	50.01% - 75% Above Average Adoption	75.1% - 99% Substantial Adoption	100% Full Adoption
GPS systems	53.41%	63.12%	11.93%	16.05%	14.22%	5.51%	14.22%	38.07%
Automatic collision notification (ACN) systems	4.17%	20.64%	46.67%	0.00%	0.00%	40.00%	0.00%	13.33%
Automatic vehicle identification (AVI) system	9.88%	58.75%	15.79%	15.79%	7.89%	10.53%	10.53%	39.47%

Driver Performance and Driver Assistance/Regulation Technologies

Driver performance monitoring and driver assistance/regulation technologies are defined as a type of safety technology that is installed on the truck for the purposes of improving the driver's truck driving performance. Additionally, some of these safety technology systems record driver performance, which then enables the firm to study the driving behavior of its employees. Table 8 provides the list of survey items that were used to measure driver performance and driver assistance/regulation technologies. Driver performance and driver assistance/regulation technologies consist of on-board closed-circuit television cameras (CCTV), electronic log-books, on-board trip computers, rear-vision television cameras, real-time traffic and weather notification systems, route-guidance (directions) and dispatching systems, vision-enhancement technology, fatigue management technology, and vehicle speed regulators. For example, the Federal Motor Carrier Safety Administration (FMCSA) is studying how fatigue management technology can enable the vehicle's dispatch center to monitor the physical conditions of the driver.

Fatigue management technology consists of electro-optical systems and sensors that monitor both thedriver's eye movement and heart-beat to measure the driver's ability to perform on-the-job driving functions (U.S. Department of Transportation 2005a).

Table 8: Driver Performance and Driver Assistance/ Regulation Technologies

Safety Technology	Notes
On-board closed-circuit television cameras (CCTV)	On-board cameras record the driver's operating performance.
Electronic log-books (software)	Electronic log-books monitor driver performance, automate the drivers' hours-of-service, and present the vehicle performance to inspectors. (Siricomm 2006; and U.S. Department of Transportation 1999)
On-board trip computers	On-board computers collect data on engine speed (RPM), idle time, and odometer reading. (U.S. Department of Transportation 1999)
Rear-vision television cameras	(Intec Video 2002; Transportation Research Board 2003; and New York Times 2001)
Real-time traffic and weather notification system (software)	This software provides the driver with changes in road conditions including heavy traffic, dangerous routes, and other hazardous situations. (National Science Foundation 2005)
Route-guidance (directions) and dispatching systems (software)	These systems provide the driver, dispatcher, and authorized third parties with information and directions about travel routes. (Qualcomm 2004)
Vision-enhancement technology	Vision-enhancement technology helps the driver operate the vehicle in poor visibility conditions (such as in foggy conditions or evening hours). (Barco 2004)
Fatigue management technology	This technology allows the vehicle's dispatch center to monitor the physical conditions of the driver. Examples of this technology include electro-optical technologies to monitor driver's eye movement; and sensors to monitor the driver's heart-beat. (U.S. Department of Transportation 2005a)
Vehicle speed regulators	This is a technology that automatically regulates a vehicle's speed based on a pre-selected point.

The results from this part of the survey demonstrate that these technologies are being adopted. Table 9 provides a description of the survey results. For firms that have adopted safety technologies, there are several driver performance and driver assistance/regulation technologies that have been fully adopted (in use by all of a firm's vehicles) including vehicle speed regulators (63.79%), route-guidance (directions) and dispatching systems (software) (57.73%), and on-board trip computers (48.86%). Moreover, vehicle speed regulators are the most widely adopted technology (60.40%) based on the percentage of firms with at least some adoption.

Table 9: Results - Driver Performance and Driver Assistance/ Regulation Technologies

Safety Technology	% > 0% Adoption	Mean > 0% Adoption	0.001% - 5.00% Minimal Adoption	5.01% – 25% Partial Adoption	25.01% - 50.0% Moderate Adoption	50.01% - 75% Above Average Adoption	75.1% - 99% Substantial Adoption	100% Full Adoption
On-board closed-circuit television cameras (CCTV)	4.68%	11.01%	70.59%	17.65%	0.00%	11.76%	0.00%	0.00%
Electronic log-books (software)	13.79%	47.39%	22.22%	29.63%	3.71%	3.70%	7.41%	33.33%
On-board trip computers	43.95%	71.01%	7.39%	13.63%	9.66%	5.68%	14.78%	48.86%
Rear-vision television cameras	13.33%	36.93%	33.96%	18.87%	13.21%	11.32%	13.21%	9.43%
Real-time traffic and weather notification system (software)	4.69%	38.89%	17.65%	29.41%	17.65%	11.76%	5.88%	17.65%
Route-guidance (directions) and dispatching systems (software)	24.32%	72.05%	14.43%	7.22%	7.22%	4.12%	9.28%	57.73%
Vision-enhancement technology	5.67%	44.39%	28.57%	19.05%	9.52%	0.00%	19.05%	23.81%
Fatigue management technology	1.48%	23.67%	50.00%	0.00%	0.00%	25.00%	25.00%	0.00%
Vehicle speed regulators	60.40%	83.90%	2.88%	7.82%	5.35%	7.41%	12.75%	63.79%

Vehicle Performance and Monitoring Technologies

Vehicle performance technologies are defined as a type of safety technology that is installed on the truck for reducing the risk that the truck crashes into obstacles or loses operational control. Additionally, some of these safety systems record vehicle performance, which then enables the firm to study the behavior of its physical systems.

Table 10 provides the list of survey items that were used to measure vehicle performance and monitoring technologies. Vehicle performance and monitoring technologies consist of systems that enable you to manage the carrying and distribution of HAZMAT cargo, adaptive cruise control, obstacle detection systems, lane change or road departure warning systems, and vehicle stability systems to prevent rollover crashes. Several vehicle manufactures are experimenting with adaptive cruise control systems for use in both the commercial and consumer auto industries. For example, Ford Motor Company is developing an adaptive cruise control system that uses radar technology that will allow a vehicle to maintain a safe distance between other vehicles. If this distance becomes too short, then the vehicle automatically adjusts its speed (Ford Motor Company 2006).

Table 10: Vehicle Performance Monitoring Technologies

Safety Technology	Notes
Systems that enable you to manage the carrying and distribution of HAZMAT cargo	An example of this technology is a hazardous materials package inspection software program that is used by shippers and carriers to track and monitor hazardous materials. (U.S. Department of Transportation 2004)
Adaptive cruise control	Adaptive cruise control systems use a radar technology that allows the vehicle to maintain a safe distance between vehicles. If this distance becomes too short, then the vehicle automatically adjusts its speed. (Ford Motor Company 2006)
Obstacle detection systems	Obstacle detection systems use closed-circuit television, infrared, or low frequency radar detection to alert the driver of a potential crash into an obstacle in the road. (U.S. Department of Transportation 2006)
Lane change or road departure warning systems	Lane change or road departure warning systems are usually vision-based lane trackers. These systems predict when the driver is in danger of switching the lane or departing the road, and trigger an alarm to warn the driver. (California Engineer 2003; and Iowa State University 1996)
Vehicle stability systems to prevent rollover crashes	(Transportation Research Board 1994; Volvo Corporation 2001; and U.S. Department of Transportation 2005b)

The results from the survey provide evidence that the motor carrier industry is at the early stages of adoption of vehicle performance and monitoring technologies. Table 11 provides a description of the results of the survey. For firms that have adopted safety technologies, there are several vehicle performance and monitoring technologies that have been fully adopted (in use by all of a firm's vehicles), including vehicle speed regulators for HAZMAT cargo systems (52.94%), adaptive cruise control (23.68%), and lane change or road departure systems (13.33%).

Table 11: Results – Vehicle Performance Monitoring Technologies

Safety Technology	% > 0% Adoption	Mean > 0% Adoption	0.001% - 5.00% Minimal Adoption	5.01% – 25% Partial Adoption	25.01% - 50.0% Moderate Adoption	50.01% - 75% Above Average Adoption	75.1% - 99% Substantial Adoption	100% Full Adoption
Systems that enable you to manage the carrying and distribution of HAZMAT cargo	9.65%	67.00%	11.76%	14.71%	5.88%	2.94%	11.77%	52.94%
Adaptive cruise control	9.83%	39.69%	36.84%	13.16%	10.53%	13.15%	2.64%	23.68%
Obstacle detection systems	9.88%	29.35%	36.84%	26.32%	13.16%	5.26%	7.89%	10.53%
Lane change or road departure warning systems	7.90%	25.83%	50.00%	20.00%	6.67%	10.00%	0.00%	13.33%
Vehicle stability systems to prevent rollover crashes	8.66%	16.88%	54.55%	27.27%	6.06%	6.06%	0.00%	6.06%

Vehicle Maintenance Technologies

Vehicle maintenance technologies are defined as safety technology systems that are installed on the truck for identifying mechanical problems due to the normal wear and tear of use of the truck. Additionally, some of these safety technology systems record vehicle equipment performance for future maintenance purposes. Table 12 provides the list of survey items that were used to measure vehicle maintenance technologies. Vehicle maintenance technologies consist of real-time communication systems which transmit vehicle performance information from the truck to the company's vehicle dispatcher while the vehicle is in use, under the hood diagnostic tools such as digital engine analyzers either in real-time or on a scheduled basis, on-board electronic vehicle management systems (EVMS), and automatic tire pressure gauges that provides computer read-outs and monitoring capabilities.

An electronic vehicle management system (EVMS) is an example of a vehicle maintenance technology that the firm can use to collect information about potential mechanical issues that may lead to poor safety performance. For example, an EVMS records vehicle speed, idle time, hard accelerations and decelerations, and engine diagnostic trouble codes (Netsix FleetPulse 2006).

Table 12: Vehicle Maintenance Technologies

Safety Technology	Notes
Real-time communication systems which transmit vehicle performance information from the truck to the company's vehicle dispatcher while the vehicle is in use.	(Information Week 2004)
Under the hood diagnostic tools such as digital engine analyzers either in real-time or on a scheduled basis	(Electronics Express 2003)
On-board electronic vehicle management systems (EVMS)	(Netistix FleetPulse 2006)
Automatic tire pressure gauges that provides computer read-outs and monitoring capabilities	

The results of the survey demonstrate that vehicle maintenance technologies are being adopted. Table 13 provides a description of the survey results. For firms that have adopted safety technologies, both EVMS and under the hood diagnostic tools have been fully adopted (in use by all of a firm's vehicles) by 49.79% and 48.54% of the firms that responded to the survey. EVMS is the most widely adopted technology in this category (59.7%) based on at least some adoption by firms in the survey. The next most widely adopted technologies are under the hood diagnostic tools (52.0%) and real-time communication systems (22.7%).

Table 13: Results – Vehicle Maintenance Technologies

Safety Technology	% > 0% Adoption	Mean > 0% Adoption	0.001% - 5.00% Minimal Adoption	5.01% – 25% Partial Adoption	25.01% - 50.0% Moderate Adoption	50.01% - 75% Above Average Adoption	75.1% - 99% Substantial Adoption	100% Full Adoption
Real-time communication systems which transmit vehicle performance information from the truck to the company's vehicle dispatcher while the vehicle is in use.	22.72%	62.27%	16.67%	14.44%	8.89%	6.67%	12.22%	41.11%
Under the hood diagnostic tools such as digital engine analyzers either in real-time or on a scheduled basis	52.00%	74.22%	3.88%	11.17%	14.08%	6.79%	15.54%	48.54%
On-board electronic vehicle management systems (EVMS)	59.70%	75.45%	4.18%	11.30%	11.30%	7.53%	15.90%	49.79%
Automatic tire pressure gauges that provides computer read-outs and monitoring capabilities	9.43%	25.16%	38.89%	33.33%	11.11%	0.00%	5.56%	11.11%

Technology Adoption By Category

This chapter will now present information about which firms have adopted safety technologies across the five main categories of technology adoption. The technology adoption by category is defined in terms of those firms that have adopted any technology in each of the five main technology adoption categories. For example, in the driver communication technologies category, if the firm adopted any driver communication technology, the firm is considered an adopter within this category. As depicted in Table 14, the most widely adopted technology category (based on the percentage of firms in the sample with at least some adoption of the technology) is driver communication technologies (94.94%).

The next most widely adopted technology categories are driver performance and driver assistance/regulation technologies (73.73%) and vehicle maintenance technologies (69.40%). The average number of firms in our sample adopted over three technology categories (see Table 15). Table 16 provides more insight into the frequency of technology adoption by firm. Moreover, the average number of individual safety technologies adopted is 6.03.

Table 14: Technology Adoption by Category

Category	Driver Communication Technology	Vehicle Communication Technology	Driver Performance & Driver Assistance/Regulation Technology	Vehicle Performance Monitoring Technology	Vehicle Maintenance Technology
Mean	94.94%	54.46%	73.73%	23.13%	69.40%
Std. Dev.	21.94%	49.86%	44.06%	42.22%	46.14%

Table 15: Average # of Technology Category Adoption

Category	Average # of Technology Category Adoption
Mean	3.16
Std. Dev.	1.31

Table 16: Number of Technologies Adopted

Number of Technologies Adopted	Number of Firms Adopting	Percent of Firms Adopting
0	149	35.90%
1	81	19.52%
2	40	9.64%
3	43	10.36%
4	27	6.51%
5	19	4.58%
6	11	2.65%
7	18	4.34%
8	11	2.65%
9	10	2.41%
10	2	0.48%
11	2	0.48%
12	1	0.24%
13	1	0.24%

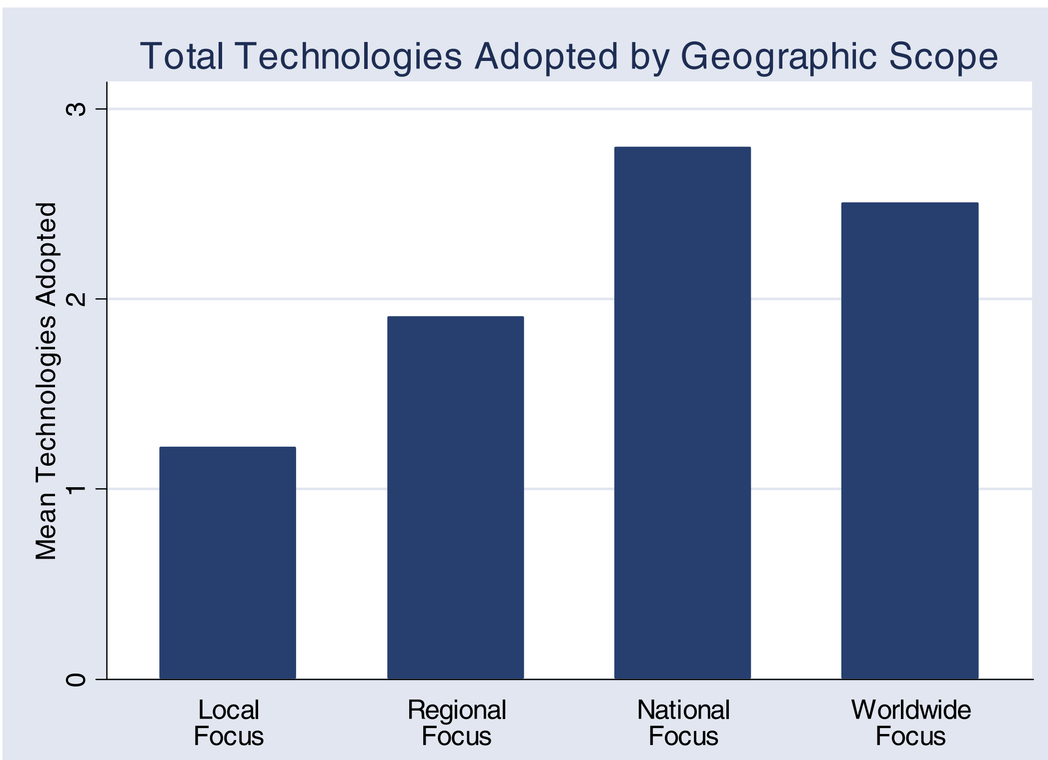
Aggregate Technology Adoption by Type of Firm

The next part of the analysis turns to an aggregate examination of technology adoption by firm characteristic. Aggregate technology adoption is defined as the total number of safety technologies adopted by the firm. The aggregate safety technology construct is operationalized as a continuous variable that can have a value between 0 and 26. There are a total of 26 individual safety technologies in the survey. Firm characteristics are defined along the following dimensions: geographic scope, size of firm, and load type. A firm can have a geographic scope of operations on a local, regional, national, or worldwide basis. Firm size is measured in terms of a firm's sales. Lastly, in our analysis, we examine less-than truckload (LTL), truckload (TL), and both LTL and TL. The analysis will next examine aggregate safety adoption along each of these firm characteristic dimensions.

Technology Adoption by Geographic Scope of the Firm

Figure 1 provides a depiction of the results which examines aggregate technology adoption by geographic scope of the firm. As the firm's geographic scope of operations increases, there is a greater level of firm adoption of safety technologies. Table 17 presents results from an ANOVA regression model. There is a statistical mean difference (p<.01) in aggregate technologies adopted based on a firm's geographic scope of operations between LOCAL (mean = 1.216) and NATIONAL (mean = 2.793) and REGIONAL (mean = 1.90) and NATIONAL.

Figure 1: Total Technologies Adopted by Geographic Scope



(1) Local: Mean = 1.216; SD = 1.856; and n = 37
(2) Regional: Mean = 1.90; SD = 2.36; and n = 175
(3) National: Mean = 2.793; SD = 3.01; and n = 164
(4) Worldwide: Mean = 2.50; SD=2.93; and n = 32

Table 17: Firm Geographic Scope

(I) Geoscope	(J) Geoscope	Mean Difference (I-J)	Std. Error	Sig.
Local	Regional	-.6866	.4796	.480
	National	-1.5765(*)	.4824	.006
	Worldwide	-1.2838	.6399	.187
Regional	Local	.6866	.4796	.480
	National	-.8898(*)	.2881	.011
	Worldwide	-.5971	.5096	.645
National	Local	1.5765(*)	.4824	.006
	Regional	.8898(*)	.2881	.011
	Worldwide	.2927	.5123	.941
Worldwide	Local	1.2838	.6399	.187
	National	.5971	.5096	.645
	Regional	-.2927	.5123	.941

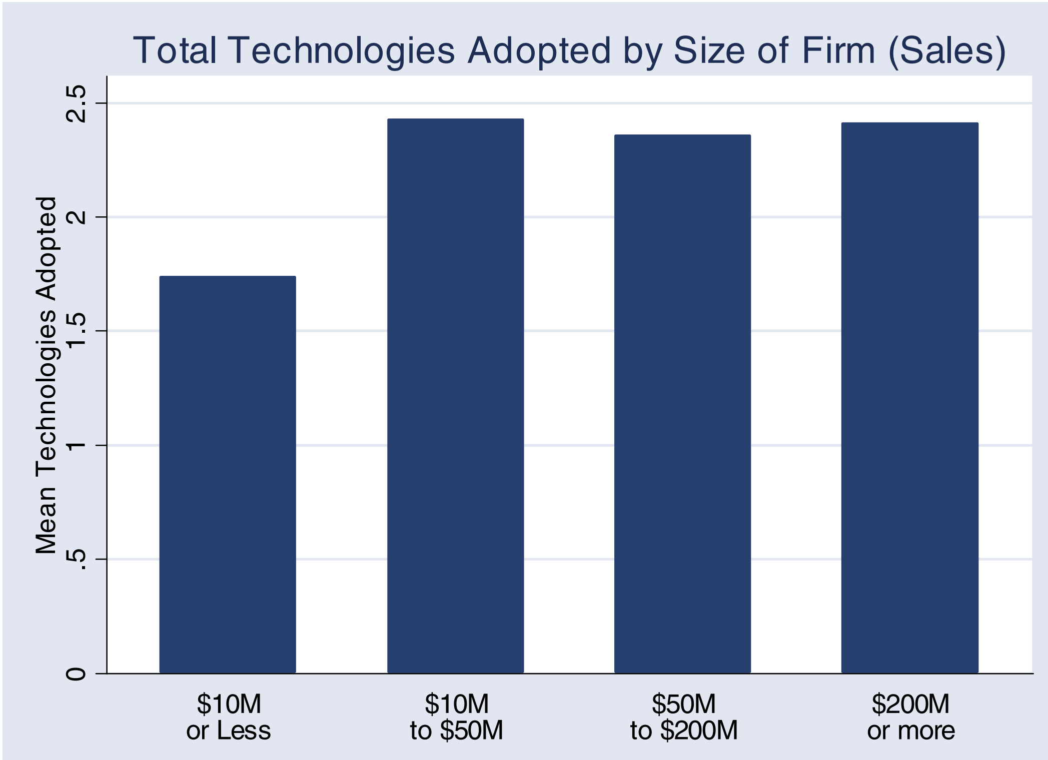
* The mean difference is significant at the .05 level.

Dependent Variable: Total Safety Technologies Adopted
Tukey HSD

Technology Adoption by Size of Firm

Figure 2 provides a depiction of the results which examines aggregate technology adoption by firm sales. As the firm's sales increase, there is a greater level of firm adoption of safety technologies. There isn't a statistical mean difference in aggregate technologies adopted based on a firm's sales.

Figure 2: Total Technologies Adopted by Size of Firm

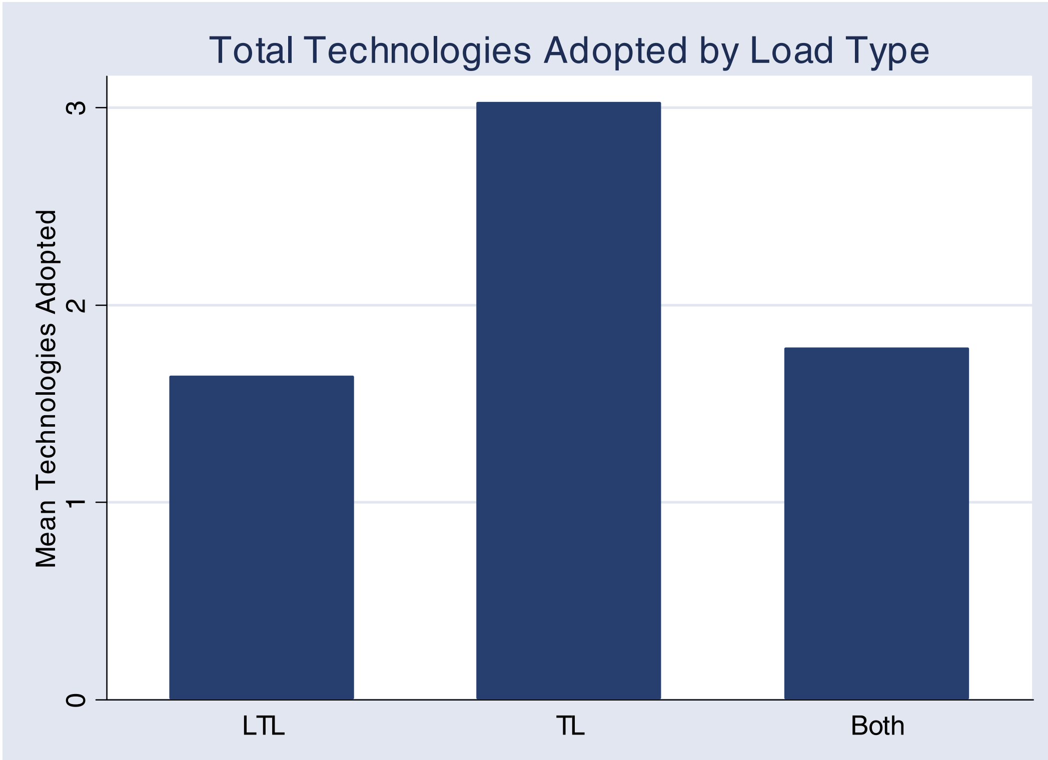


(1) $10M or Less: Mean = 1.73; SD = 1.67; and n = 53
(2) $10M - $50M: Mean = 2.43; SD = 2.72; and n = 101
(3) $50M - $200M: Mean = 2.36; SD = 3.02; and n = 98
(4) $200M or more: Mean = 2.41; SD = 2.77; and n = 110

Technology Adoption by Load Type

Figure 3 provides a depiction of the results which examines aggregate technology adoption by a firm's load type. Table 18 presents results from an ANOVA regression model. There is a statistical mean difference ($p<.01$) in aggregate technologies adopted on the basis of a firm's load type between LTL (mean = 1.635) and TL (mean = 3.022) and between TL and BOTH (1.780).

Figure 3: Total Technologies Adopted by Load Type



(1) LTL: Mean = 1.635; SD = 2.11; and n = 52
(2) TL: Mean = 3.022; SD = 2.94; and n = 179
(3) Both: Mean = 1.78; SD = 2.45; and n = 131

Table 18: Load Type

(I) Loadtype	(J) Loadtype	Mean Difference (I-J)	Std. Error	Sig.
LTL	TL	-1.3877(*)	.4194	.003
	Both	-.1440	.4364	.942
TL	LTL	1.3877(*)	.4194	.003
	Both	1.2437(*)	.3061	.000
Both	LTL	.1440	.4364	.942
	TL	-1.2437(*)	.3061	.000

* The mean difference is significant at the .01 level.

Dependent Variable: Total Safety Technologies Adopted
Tukey HSD

Summary and Conclusion

We have investigated one type of safety management practice that firms in this industry are embracing – safety technology adoption. We have developed and administered a unique and comprehensive survey of safety technology adoption to large firms in the U.S. Motor Carrier industry. Our motor carrier survey provides a strong picture of the current level of firm safety technology adoption in five key areas of information technology safety management practice. Therefore, our survey contributes to the literature by providing insight into both the adoption levels of specific types of safety management technologies and how these safety technologies are being adopted by different types of organizations.

Our results demonstrate that the U.S. Motor Carrier industry is at the early stages of safety technology adoption in most of the safety technology management dimensions that we investigated. The empirical evidence suggests that it is the firms that have organizational resources to adopt safety management technologies that are initiating safety technology adoption. For example, it is readily apparent that large firms that operate over long distances are the leaders in safety management technology adoption. Lastly, many of the firms in our survey have adopted at least three types of safety management technologies.

To the best of our knowledge, this is the first empirical study examining adoption of safety specific technologies in the context of large firms in the U.S. Motor Carrier industry.

Previous safety management literature has examined the organizational determinants of safety performance. Additionally, the safety management literature has examined various aspects of safety management motor carrier technology. Our study complements and contributes to the stream of motor carrier safety management technology adoption literature.

Our study has important managerial implications. First, the results of our study can assist firm managers with understanding which safety management technologies are currently being evaluated by the largest motor carriers in the United States. As a result, small and medium-sized carriers can learn what types of safety technologies leader firms are currently adopting. Therefore, our study provides solid information about the current adoption trends of safety specific technologies among the largest motor carriers. Second, firm managers can begin to evaluate how the safety technology adoption levels of individual firms is contributing to safety performance. The results of our study can begin to provide insight into which types of safety management technologies can be used to improve firm safety performance. While our study examines the current adoption level of the largest carriers, future studies could begin to explore the relationship between firm safety technology adoption and safety performance. Lastly, safety management officials can begin exploring which types of safety management technologies should be required of all motor carriers to improve safety performance.

Through the use of future studies, safety management officials can begin evaluating the cost and benefits of each technology including the extent to which adoption of specific safety management technologies may lead to improved safety performance. Therefore, our study begins a very important discussion that can provide input into the rule making process.

Chapter 4: Driving for Safety: An Examination of Safety Technology Adoption and Firm Safety Performance in the U.S. Motor Carrier Industry

Introduction

Annually, in the United States, there are over 400,000 motor vehicle crashes resulting in over 100,000 injuries and fatalities (U.S. Department of Transportation 2006). These crashes involve significant negative impact at each of the following levels: economic (loss of life, loss of work time due to injuries), societal (environmental clean up due to spills of hazardous materials, repair to roadways, and property damaged in crashes) and firm level (equipment damage/loss, revenue loss to motor carriers, and cargo damage/loss to the shipper). In fact, it has been estimated that motor vehicle crashes on an annual basis result in $230 billion in lost economic value due to the economic and societal costs that are incurred to recover from these incidents (NHTSA 2006). To the extent that the policies and practices of motor carrier management can minimize the occurrence of vehicle crashes, these losses could be substantially lessened. The focus of this investigation is on the examination of a link between the motor carrier's investment in safety technologies and observed crash rates at the firm level.

The impact of crashes on the individual motor carrier firms is particularly significant. First, each crash involves significant losses to the carriers in terms of equipment repairs or the costs to replace destroyed equipment.

Second, there are legal expenses involved in settling any post-crash claims from shippers, from drivers and/or passengers in other vehicles involved, or from pedestrians or property owners. Third, there is the impact of future lost sales if the crash creates a negative image regarding the safety practices of the carrier and results in canceled orders/contracts. Fourth, there could be an increase in insurance rates as a consequence of settled claims stemming from the crash. Fifth, there are costs associated with the employment of replacement drivers as a result of injuries and/or fatalities to the drivers involved. Recognizing that the profit margins in the motor carrier industry is quite thin and that the carriers face a significant shortage of qualified drivers (with valid Commercial Drivers Licenses), the impact of motor carrier crashes is even more severe. Clearly, there are no shortage of reasons bringing the issue of motor carrier safety to the top of a motor carrier manager's policy agenda.

Indeed, researchers in the general field of operations management have placed increasing emphasis on the workplace environment/management practices and safety outcomes. Many of these studies demonstrate that firms adopt policies and practices that contribute to an unsafe environment and higher accident rates. Brown et al (2001) examine individual level factors that contribute to accidents in the U.S. Steel Industry and find that safety hazards, safety culture, and production pressures (all within the purview of the management policies and practices of the firm) can lead to unsafe employee behaviors. In a study of petrochemical plants and refineries, Wolf (2001) provides empirical support that chemical plants that are larger, adhere to tightly coupled processes and systems, and operate highly complex equipment will suffer higher accident rates.

Star (2001) highlights the importance of refocusing production and operations management research to safety management issues especially since the terrorist events of September 11, 2001. Lastly, Kleindorfer and Saad (2005) provide a conceptual framework that demonstrates the importance of understanding the factors that contribute accidents in the U.S. Chemical Industry. The emphasis of these studies is examining operating environments, in large part, dictated by management policies and practices that have a direct impact on the level of accidents in the plant environment. Indeed, there are operations management studies demonstrating that management practices and policies can also lower accident rates and create a safer environment. McFadden and Hosmane (2001) demonstrate that an alcohol related screening program (even though this safety management practice is mandated by federal legislation and not necessarily initiated by the firm, itself) does, in fact, lead to a reduced probability of accidents by commercial airline pilots in the U.S. Airline Industry.

There is a body of literature that has addressed the link between motor carrier management practices and policies and crash rates of the individual motor carriers. Mejza and Corsi (1999) and Mejza, Barnard, Corsi and Keane (2003) provide evidence on the role of motor carrier management practices in enhancing motor carrier safety performance. Crum and Morrow (2002) studied carrier scheduling practices as part of an overall effort to link greater driver fatigue with a higher likelihood of crashes.

Therefore, a key finding is that carrier practices to create driver-friendly schedules, which allowed for adequate opportunities for rest, would have a positive impact on lowering carrier crash rates. Corsi and Fanara (1988) suggest that there is empirical evidence between driver turnover rate and driver hours of service and accident rates. Thus, carrier policies to improve driver working conditions and lower turnover rates would presumably have a positive impact on lowering crash rates for the individual firms.

As discussed in Chapter 3, one important safety management policy/practice that has been unexplored, however, is the adoption of specific safety management technology resources and the relationship to safety performance. Safety management technology resources are defined as the physical information technology applications that may be used for the purposes of monitoring and alerting the firm to impending failures in either the internal or external operating environment. Examples of safety management information technologies include: on-board computers, anti-rollover technologies, and collision-avoidance devices.

Although there have been several studies that have examined the relationship between information technology resources on firm financial and/or operating performance, to the best of our knowledge, there has been limited research on the linkage between a firm's safety specific management technology resources and firm safety performance.

As highlighted in the previous chapters, although many researchers have examined the effect of IT investment on firm performance, few researchers have explored the relationship between specific types of safety technology resources and firm safety performance. This chapter builds upon the methodology and data analysis as described in Chapter 3 to build a unique model that explores the relationship between safety technology resources and firm safety performance.

Boyer, Swink and Rosenzwieg (2005) recently suggest that the information systems strategy literature may serve as a guide to understand how the adoption of tangible IT and intangible IT resources is linked to firm performance. Consistent with Boyer, Swink and Rosenzwieg (2005) and Amundson (1998), through the lens of the resource-based view of the firm (RBV), this dissertation develops a unique model of IT adoption and firm safety performance (Bharadwaj 2000). Specifically, this dissertation investigates how the relationship between a firm's tangible IT resources and intangible IT resources may be related to firm safety performance.

This study contributes to the operations management literature on safety management by developing and empirically testing a unique model of safety technology resource and safety performance. This model is grounded in the resource-based view of the firm. Through this theoretical perspective, a solid basis for developing hypotheses on the relationship between safety technology resources and firm safety performance is provided.

This theoretical framework is tested through a comprehensive survey instrument that was administered through sponsorship provided by the Federal Motor Carrier Safety Administration of the United States Department of Transportation.

The rest of this chapter is organized as follows. In Section 2, the theoretical framework and arguments of the hypotheses are presented. The research methodology and data collection procedures are presented in Section 3. Section 4 contains the results of the model. Lastly, Section 5 contains a discussion of our results and conclusion.

The Theoretical Relationship Between Safety Technology Resources and Safety Performance

In today's global economy, many firms are increasingly operating away from the traditional physical boundaries of the firm. As the firm expands its geographic scope of operations into more distributed settings, it becomes exposed to greater levels of environmental uncertainty, which contributes to an increased risk of accidents. For example, as employees travel to remote locations to interact with their customers, it becomes difficult for the firm's managers to monitor and coordinate employee behavior. Moreover, as a firm's employees venture outside the physical confines of the firm, there is a greater level of risk that a firm's employees will take chances and expose themselves or the firm to unnecessary risks, often to satisfy a customer's requests for services. This situation is particularly relevant for firms in the U.S. Motor Carrier Industry.

As a result, it is very important to consider the types of resources that may enable the firm to reduce its exposure to external environmental uncertainty and to the risk of accidents/crashes. Therefore, it is very important to understand how the firm can invest in safety specific technology resources to reduce its exposure to unsafe situations that increase the likelihood of accidents/crashes.

As described in Chapter 2, the resource-based view of the firm (RBV) serves as an excellent framework for this study. The RBV theoretical lens, as developed by Barney (1991;1995), is used to explain how a firm's investment in tangible and intangible resources may serve as a sustainable source of competitive advantage in dynamically evolving markets. As previously described, a firm's resources are defined as those tangible and intangible resources which are difficult to copy, difficult to imitate, rare, and not able to be imitated. Examples of tangible resources include the firm's physical plant, property, and equipment that are designed and produced through proprietary and secret processes, systems, and production methods. Moreover, the firm's resources also consist of intangible resources, which are the unique combination of the firm's values, priorities, top management know-how, and competencies to deliver superior levels of firm performance. Examples of intangible resources include superior levels of customer service, enhanced product quality, and increased responsiveness to environmental conditions (Bharadwaj 2000).

Use of RBV in Firm Performance Research

The resource-based view of the firm, as developed by Bharadwaj (2000), is drawn upon to examine how safety specific technology resources may be linked to firm safety performance. Specifically, following the work of Bharadwaj (2000), we investigate the role that tangible technology resources relate to firm safety performance – i.e., safety-specific physical technology resources. First, adopting Bharadwaj's (2000) definition of tangible IT resources, safety-specific technology resources may include the software and hardware safety platforms that enable the firm to monitor and alert its employees to unsafe situations in its operating environment. Although some of these safety-specific technology resources may be viewed as a commodity, consistent with Bharadwaj (2000), we suggest firms do uniquely adapt, configure, and maintain their safety specific technology resources. It is this unique integration process that is imperfectly understood. Therefore, consistent with Bharadwaj (2000), we suggest that the firm's tangible safety resources may be negatively related to a firm's involvement in crashes.

We also examine the intangible dimension of IT resources related to safety performance. IT intangible resources include the unique combination of the firm's physical safety technology resources and its technical and managerial know-how (Bharadwaj 2000). Information technology can generate value for the firm when it leverages pre-existing firm resources. Therefore, the firm's unique knowledge base in pre-existing areas in combination with its adoption of safety technologies can generate unique value for the firm.

Consistent with Bharadwaj (2000), we suggest that the firm's intangible safety resources may be negatively related to a firm's involvement in crashes.

Next, this dissertation presents specific hypotheses based upon both the resource-based theory of the firm.

Safety Technology Resources and Firm Safety Performance

The firm's investment in physical safety technology resources is its tangible IT resource. There are two fundamental ways that safety specific technology resources may be related to firm safety performance. First, the firm may configure its physical safety technology resources to effectively monitor and manage the behavior of its employees. As the firm integrates physical safety technology resources into the fabric of its organization, the firm can become alerted in real-time to poor employee behavior through the use of its physical technology assets. For example, as a part of its ERP implementation, Federal Express Corporation configured its physical technology resources to collect and analyze job-related safety violations of its employees (Palvia, Perkins, and Zettleman 1992). Examples of job-related safety violations include drug testing violations, misuse of the firm's materials and equipment, and other legal and ethical misconduct. Moreover, some firms are investing in fatigue management technologies to monitor in real-time the heart-rate, alertness, and other physical characteristics of employees who are exposed to strenuous and hazardous working conditions. In this way, these firms are able to take proactive measures to prevent its employees from becoming involved in unsafe situations.

Similarly, the firm may configure its physical safety technology resources to track the usage and movement of its materials and equipment.

As the firm makes increased investments in physical safety technology resources, the firm's managers will have real-time access to performance information about whether or not the firm's materials and equipment are being used beyond acceptable and safe operating limits. For example, in the U.S. Nuclear Power Plant Industry, firms use information technology to monitor the temperature of nuclear reactions that occur in their facilities. If the temperature of these facilities reaches unacceptable limits, the nuclear power plants' IT systems provides instant alerts that a potentially unsafe situation may arise. Similarly, in the U.S. Aviation Industry, the Federal Aviation Administration's air traffic control system relies on sophisticated information technology systems to coordinate the flow of commercial airline traffic. The FAA's ATC system provides instant information on the speed, location, and other coordination information in real-time. Lastly, in the U.S. Motor Carrier Industry, many firms are investing in anti-rollover technologies that may reduce the likelihood of roll-over crashes from occurring (Ford Motor Company 2006). In many of these examples, firms are investing in information technology resources to prevent catastrophic crashes from arising. Therefore, these arguments lead to the following hypothesis:

H5: The greater the investment in safety technology resources the better the firm's safety performance.

The firm's intangible safety technology priority resources is defined as the unique combination of the firm's priority to safety and its current safety technology resources.

The firm's intangible safety technology priority resources may be positively related to firm safety performance in three unique ways. First, through management's safety as a priority vision, the firm's employees are encouraged to seek innovative safety technology software and hardware applications that can be used to manage the behavior of the firm's human and physical resources (Armstrong and Sambamurthy 1999; Naveh et al 2005). For instance, Armstrong and Sambamurthy (1999) describe how firm's that show high levels of commitment and business leadership to the use of IT systems may improve firm performance. Therefore, through solid business and technology leadership, the top management team can encourage the organization to develop innovative ways to use technology resources for safety purposes.

Second, the benefits of intangible safety technology priority resources can be found when the firm's IT staff and safety managers experiment with creating driver safety management technologies. Indeed, experimental driver safety management technologies are being evaluated by firms in the U.S. Motor Carrier Industry.
For example, some firms are experimenting with biometric devices that monitor the eye movements of a firm's truck drivers (U.S. Department of Transportation 2005).

Through the use of biometric technologies, the firm can monitor the ability of the driver to respond to sudden and unexpected events that the driver may experience while driving long distances. If the firm's drivers have a diminished ability to react instantly to unexpected events, the firm's headquarters may take immediate steps to remove the firm's drivers from operating its equipment. As a result, the firm may become less exposed to events that could lead to unsafe situations.

Third, the benefits of intangible safety technology priority resources can be found when the firm's IT staff and safety managers experiment with creating vehicle safety management technologies. Vehicle safety management technologies may provide better management and monitoring of the status and conditions of the firm's physical equipment. In firms that are committed to safety as a priority, the firm's employees are willing to experiment with technologies that may improve the safe utilization of the firm's physical equipment. In the U.S. Motor Carrier Industry, physical equipment failure can lead to catastrophic consequences. For example, some firms are equipping their vehicles with anti-roll over technologies that enable the vehicle to dynamically stabilize its load so that the truck doesn't accidentally turn-over (Ford Motor Company 2006). These arguments lead to the following hypothesis:

H6: The greater top management's emphasis on safety as a priority, the greater the effect of investment in safety technology resources on improving the firm's safety performance.

The second intangible resource is the firm's intangible safety technology knowledge resources. Intangible safety technology knowledge resources are the unique combination of the top management team's knowledge of safety technology resources and its current safety technology resources. The firm's intangible safety technology resources may be positively related to firm safety performance in two specific ways. First, the firm's top management team can create a vision statement, explicit knowledge documents, and specific guidelines for using information technology to achieve the firm's safety performance (Argawal and Sambamurthy 2002). In fact, by creating a vision, knowledge and guidelines, the firm's top management team can demonstrate that it is committed to using information technology as a strategic opportunity to achieve better safety performance (Chatterjee, Pancini, and Sambamurthy 2002).

The second way that the firm's intangible safety technology knowledge resources may be related to firm safety performance is through the explicit sharing of how its competitors and government regulators are pursuing safety technology resource adoption. As described by Chatterjee, Pacini, and Sambamurthy (2002), the firm's top management can send a powerful signal to the rest of the firm's managers by distributing information to the firm's employees on how both its competitors are adopting information technology resources and what government regulators are requiring in terms of use of safety technology resources.

Therefore, by explicitly sharing this information with its employees, the firm's top management team encourages its employees to expend their time and energy in making sense of how information technology can be used to improve firm safety performance. The firm's employees are then empowered to explore ways in which safety technology resourcescan be used as a safety management practice. These arguments lead to the following hypothesis:

H7: The greater the top management's knowledge of safety technology resources, the greater the effect of investment in safety technology resources on improving the firm's safety performance.

The third intangible resource is the firm's intangible safety technology competency resources. Intangible safety technology competency resources are the unique combination of the firm's IT staff competency and its current safety technology investments. The firm's intangible safety technology competency resources may be positively related to firm safety performance in two specific ways. First, the firm can benefit from its intangible safety technology competency resources because its IT staff has a unique understanding of the barriers to successfully implementing safety technology resources within the boundaries of the firm. Many safety technology resources are unique to most organizations. Therefore, a highly competent IT staff will be able to effectively manage the end-to-end processes associated with implementing safety technology resources.

The second way a firm can benefit from its intangible safety technology competency resources is by exploiting its ability to work in a collective and diverse team environment. The IT personnel will have the ability to configure and adapt safety technology resources based upon the unique requirements of diverse stakeholders including the firm's drivers, safety managers, outside government regulators and consultants. It is very unique to have the ability to interface and meet the implementation standards and requirements of a vast array of stakeholders. These arguments lead to the following hypothesis:

H8: The greater the IT personnel competency, the greater the effect of investment in safety technology resources on improving the firm's safety performance.

Methods

Data Collection

To investigate the relationship between IT and safety performance, data was collected using the procedures described in Chapter 3 of this dissertation. Briefly, the empirical context for this study is the U.S. Motor Carrier industry. Specifically, this research setting focuses on trucking companies and their adoption of safety information technology resources. The specific unit of analysis for the study is the motor carrier firm and its adoption of safety technology management practices. The reader is referred to Chapter 3 for more specific details on the data collection procedures.

Measurement of Variables

The key constructs of this conceptual framework are operationalized using several types of scales including: 1) percentage scales, 2) multi-item reflective scales, and 3) metric measures. One metric measure was derived from an archival data source obtained from the Federal Motor Carrier Safety Administration's SafeStat database.

Firm Safety Performance. In this chapter, firm safety performance represents the firm's involvement in motor carrier crashes. This construct (CRASHES-2006) is operationalized as a measure of the state reported crashes as of March 2006 (U.S. Department of Transportation 2006). The data source is the U.S. Department of Transportation's Federal Motor Carrier Safety Administration (FMCSA) SafeStat database. Additionally, through the use of this time window, this study can control for prior firm safety performance.

Safety Technology Resources. Safety technology resources (SAFETY-TECH) are defined as the firm's full adoption of physical safety technology resources. A firm's full adoption of safety technology resources is measured as the sum of 100 percent investments across any of the 26 safety technology items in the survey. Moreover, if the firm has fully adopted 100 percent of all 26 safety technology items, this firm would receive a safety technology resource score of 26. If the firm has not fully adopted any of the 26 items, then this firm would receive a safety technology resource score of 0.

SAFETY-IT-Priority. Safety IT priority (SAFETY-TECH-PRIORITY) is defined as an interaction variable that combines safety technology resources and safety as a priority. Specifically, this variable is the interaction of safety technology resources (SAFETY-TECH) and safety as a priority (PRIORITY) control variable.

SAFETY-IT-Knowledge. Safety IT knowledge (SAFETY-TECH-KNOW) is defined as an interaction variable that combines safety technology resources and management's knowledge of safety technology resources. Specifically, this variable is the interaction of safety technology resources and the top management team's knowledge of safety technologies (KNOW) control variable.

SAFETY-IT-Comp. Safety IT competency (SAFETY-IT-COMP) is defined as an interaction variable that combines safety technology resources and IT personnel competency. Specifically, this variable is the interaction of the safety technology resources and the firm's IT personnel competency (COMP) control variable.

Control variables. This model contains numerous control variables. These control variables are: firm size (SIZE), driver safety performance in 2006 (DRIVER), vehicle safety performance in 2006 (VEHICLE), the number of crashes in 2005 (CRASH-2005), the carrier type (FORHIRE), safety as a priority (PRIORITY), top management team's knowledge of safety technologies (KNOW), the IT personnel's implementation competencies (COMP) and the geographic scope of the firm (GEOSCOPE).

Firm size as measured in terms of power-units is a common measure of the slack resources in transportation studies (Christiansen et al 2004; Mejza and Corsi 1999). The number of power-units in the firm consists of the total: trucks, tractors, and hazardous material tank trucks. The quality of the non-IT resources in the firm is measured by driver and vehicle safety rating measures. Quality of non-IT capital is measured by the VEHICLE safety rating which reflects the firm's total number of vehicle violations normalized by power-units (Mejza and Corsi 1999; Mejza et al 2003). Quality of non-IT human resources is measured by the DRIVER safety rating which reflects the firm's total number driver violations normalized by power units (Mejza and Corsi 1999; Mejza et al 2003). Additionally, the carrier type of firm (FORHIRE) is also a common measure in transportation studies. A dummy variable to control for carrier type (FORHIRE) was created. If a firm's focus is on for-hire operations, the FORHIRE variable equals 1, 0 otherwise. Moreover, the firm's geographic scope (GEOSCOPE) of operations is controlled. Firms that operate across longer distance have an increased proclivity to become involved in crashes. Therefore, the geographic scope is a continuous variable that may take a value between 0 and 4 depending on the firm's type of operation (e.g., local, regional, national or worldwide).

The firm's safety management practices are also controlled through the use of three latent constructs. The firm's safety climate is controlled through the safety as a priority (PRIORITY) variable. Specifically, safety as a priority is measured by adopting four scale items from Janssens et al (1995).

Managers indicated on a scale from one to seven their level of disagreement or agreement as to the extent to which they believe that management considers safety of its employees as most important. This control variable is defined as the average of the four scale items from Janssens et al (1995). Top management team's knowledge of safety technologies (KNOW) is also controlled. We measure (KNOW) by taking the average of three scale items from Armstrong and Sambamurthy (1999). Similarly, we control for the IT personnel competency (COMP) of the firm. A highly competent IT staff can plan, organize, and lead safety technology projects. Specifically, we will measure IT personnel competency by taking the average of three scale items from Byrd and Turner (2001). Lastly, to address potential endongeniety issues we have included a firm's previous crash performance -- CRASH-2005. A summary of the variables along with descriptive statistics are found in Table 19.

Table 19: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Dependent Variable					
CRASHES-2006	400	49.69	144.917	0	1991
Independent Variable					
SAFETY-TECH	415	2.240	2.269	0	13
Control Variables					
PRIORITY	397	5.980	0.872	2	7
KNOW	397	4.790	1.030	1	7
COMP	397	5.054	1.046	1	7
SIZE	400	687.153	2331.692	1	39893
DRIVER	385	39.188	26.843	0	96.01
VEHICLE	386	41.907	24.556	0	99.98
FORHIRE	415	0.573	0.495	0	1
GEOSCOPE	408	2.468	0.767	1	4
CRASHES-2005	398	48.083	139.732	0	1921
Moderation Variables					
SAFETY-TECH-PRIORITY	397	13.791	17.055	0	87.75
SAFETY-TECH-KNOW	397	11.247	14.346	0	78
SAFETY-TECH-COMP	397	11.800	15.048	0	84

Reliability and Validity. We conducted a principal component analysis with varimax rotation to check for reliability and validity of our latent constructs. All scales were unidimensional using principal component analysis as shown in the appendix. All factors have a cronbach alpha value of α=.89 or greater which is better than the generally accepted value of α=.70. Convergent and discriminant validity was established by testing whether the items in a scale all loaded on a common factor. The appendix shows that all factors were orthogonal to each other, and that the eigenvalues of all factors exceeded the threshold of 1.0, which supports each scale's dimensionality (Hair et al. 1995). Discriminant validity can also be assessed by examining the bi-variate correlations of each of the scale measures, and there were no significant correlations above .70 ($p > .01$).

Lastly, Kaiser's measure of sampling adequacy, which measures the extent to which variables are appropriate for factor analysis, was .868, a very satisfactory level (.80 is considered "meritorious" (Kaiser and Rice 1974)).

Results

Our analysis begins with an examination of the correlation matrix as shown in Table 20. The independent variables do not show statistically significant correlation above the .70 threshold (Zhu and Kraemer 2002), which indicates that these variables are distinct. Given these results, we likely conclude that we can proceed with our model without much concern for multicollinearity.

Table 20: Correlation Matrix

	CRASHES -2006	SAFETY-TECH	SIZE	DRIVER	VEHICLE	FORHIRE	GEOSCOPE	CRASHES -2005	PRIORITY	KNOW	COMP
CRASHES-2006	1										
SAFETY-TECH	0.1744 ** (0.00)	1									
SIZE	0.516 ** (0.00)	0.015 (0.76)	1								
DRIVER	0.084 + (0.10)	0.113 * (0.03)	0.066 (0.19)	1.000							
VEHICLE	-0.077 (0.13)	-0.216 ** (0.00)	-0.073 (0.15)	0.357** (0.00)	1.000						
FORHIRE	0.215 ** (0.00)	0.266 ** (0.00)	0.098 * (0.05)	0.308** (0.00)	-0.099 * (0.05)	1.000					
GEOSCOPE	0.233 ** (0.00)	0.172 ** (0.00)	0.192 ** (0.00)	0.196** (0.00)	-0.053 (0.30)	0.113 * (0.02)	1.000				
CRASHES-2005	0.999 ** (0.00)	0.18 ** (0.00)	0.505 ** (0.00)	0.09 + (0.08)	-0.074 (0.15)	0.218 ** (0.00)	0.234 ** (0.00)	1			
PRIORITY	-0.006 (0.90)	0.151 ** (0.00)	0.004 (0.93)	-0.02 (0.70)	-0.163 ** (0.00)	0.079 (0.11)	0.021 (0.68)	-0.011 (0.83)	1.000		
KNOW	0.084 + (0.10)	0.149 ** (0.00)	0.019 (0.72)	0.045 (0.39)	-0.05 (0.34)	0.119 * (0.02)	0.101 * (0.04)	0.085 + (0.10)	0.516 ** (0.00)	1.000	
COMP	0.176 ** (0.00)	0.131 ** (0.01)	-0.007 (0.90)	0.006 (0.91)	-0.105 * (0.04)	0.006 (0.91)	0.179 ** (0.00)	0.174 ** (0.00)	0.409 ** (0.00)	0.595 ** (0.00)	1.000

** $p < .01$, * $p < .05$, + $p < .10$

A two-stage hierarchical regression modelis used to test the four hypotheses. This is an appropriate methodology for separating out the effect of the interaction terms from the impact of our direct effect construct – physical safety technology resource investment. This approach is consistent with the method suggested by Saunders (1956) and described in Carte and Russell (2003) as appropriate in testing for moderating effects.

Specifically, a direct effects model is used to test Hypotheses 5. Firm safety performance (CRASHES-2006) as measured by the firm's involvement in crashes is our dependent variable. The independent variable is: safety technology resources (SAFETY-TECH). The model is shown in the following equation:

$$\text{CRASHES-2006} = \beta_0 + \beta_1\text{SAFETY-TECH} + \gamma_1\text{PRIORITY} + \gamma_2\text{KNOW} + \gamma_3\text{COMP} + \gamma_4\text{DRIVER} + \gamma_5\text{VEHICLE} + \gamma_6\text{FORHIRE} + {}_7\text{GEOSCOPE} + \gamma_8\text{SIZE} + \gamma_9\text{CRASHES-2005}$$

To test Hypotheses 6, 7, and 8, an interaction effects model is developed. This model retains all of the variables from the direct effects model. Then the interaction variables are combined, which includes intangiblesafety technology resources priority (SAFETY-TECH-PRIORITY), intangible safety technology resources knowledge (SAFETY-TECH-KNOW), and intangible safety technology resources competency (SAFETY-TECH-COMP).

The interaction effects model is shown in the following equation:

$$\text{CRASHES-2006} = \beta_0 + \beta_1\text{SAFETY-TECH} + \beta_2\text{SAFETY-IT-PRIORITY} + \beta_3\text{SAFETY-TECH-KNOW} + \beta_4\text{SAFETY-TECH-COMP} + \gamma_1\text{PRIORITY} + \gamma_2\text{COMP} + \gamma_3\text{DRIVER} + \gamma_4\text{VEHICLE} + \gamma_5\text{FORHIRE} + \gamma_6\text{GEOSCOPE} + \gamma_7\text{SIZE} + \gamma_8\text{CRASHES-2005}$$

As described in Chapter 2, the Poisson regression model is used The reader is referred to Chapter 2 for more details as to why the Poisson regression is an appropriate method to test a model where the dependent variable consists of non-negative count data.

Table 21 presents results from the Poisson regression model. Hypothe sis 5, the greater the investment in physical safety information technology resources the better the firm's safety performance is supported. The coefficient (SAFETY-TECH) is negative and statistically significant at the 0.01 level.

In terms of the control variables, seven of the nine control variables are positive and statistically significant. Consistent with the expectation, the greater the number of driver violations (DRIVER), the more likely that the firm is involved in a crash. Moreover, larger firms (SIZE) are more likely to be involved in a crash. Similarly, for-hire firms (FORHIRE) who travel along more irregular routes, are more likely to become involved in crashes.

Firms that travel longer distances (GEOSCOPE) also have a greater likelihood of involvement in crashes.

Also, top management teams that are knowledgeable about safety technologies are less likely to be involved in crashes (KNOW). Firms that experience crashes in 2005 (CRASH-2005) experience crashes in 2006. Surprisingly, firms that make safety a priority (PRIORITY) and that are competent in managing technology projects (ITCOMP) are more likely to be involved in crashes. It is quite possible that simply making safety a priority does not lead to improvement in safety because it is difficult to create an environment for safety when there is an existence of high employee turnover. Additionally, competency in technology implementation does not lead to improvements in safety because many these firms may not have fully adopted safety technology investments at this time.

The interaction effects model is discussed next. As suggested by Saunders (1956) and described in Carte and Russell (2003), when analyzing the overall effect on a model of introducing additional terms, it is appropriate to measure the increase in statistical significance by computing an F-statistic. The F-statistic for the ΔR^2 between the direct effects model and the interaction effect model is 15.37. This indicates that the moderating effects of intangible safety technology resources priority, intangible safety technology resources knowledge, and intangible safety technology resources competency are statistically significant at the 0.01 level.

Since there is moderation, it is appropriate to examine the coefficients of the interaction terms to test Hypotheses 6, 7, and 8.

The interaction of the intangible resource variables is statistically significant. Hypothesis 6, which states the greater top management's emphasis on safety as a priority, the greater the effect of investment in safety technology resources on improving the firm's safety performance, is not supported. As seen in the second column of Table 21, the coefficient (SAFETY-TECH-PRIORITY) is positive and statistically significant at the 0.01 level which is a surprising result. Hypothesis 7, which states the greater the top management's knowledge of safety technology, the greater the effect of investment in safety technology resources on improving the firm's safety performance, is supported. From the second column in Table 21, we find the coefficient (SAFETY-TECH KNOW) is negative and statistically significant at the 0.01 level as expected. Hypothesis8, which states the greater the IT personnel competency, the greater the effect of investment in safety technology resourceson improving the firm's safety performance, is supported. As depicted in the second column of Table 21, the coefficient (SAFETY-TECH-COMP) is negative and statistically significant at the 0.01 level as expected.

Table 21: Model Results

Independent Variables	**Direct Effects** (Standard Errors)	**Interaction Effects** (Standard Errors)
SAFETY-TECH	-0.018 ** (0.00)	-0.223 ** (0.02)
PRIORITY	0.021 + (0.01)	-0.310 ** (0.02)
KNOW	-0.093 * (0.01)	0.008 (0.02)
COMP	0.192 ** (0.01)	0.365 ** (0.02)
SIZE	0.000 ** (0.00)	0.000 ** (0.00)
DRIVER	0.009 ** (0.00)	0.008 ** (0.00)
VEHICLE	-0.007 ** (0.00)	-0.007 ** (0.00)
FORHIRE	1.070 ** (0.03)	0.949 ** (0.03)
GEOSCOPE	0.681 ** (0.01)	0.538 ** (0.01)
CRASHES-2005	0.002 ** (0.00)	0.002 ** (0.00)
SAFETY-TECH PRIORITY		0.124 ** (0.00)
SAFETY-TECH KNOW		-0.041** (0.00)
SAFETY-TECH COMP		-0.060 ** (0.00)
CONSTANT	0.110 ** (0.08)	1.04 ** (0.09)
N	362	362
Pseudo R^2	0.7248	0.7570

** $p < .01$, * $p < .05$, + $p < .10$

Discussion and Conclusion

We have drawn on the resource-based view (RBV) of the firm to build a theory linking safety technology resources with firm safety performance. The resource-based view (RBV) of the firm provides us with a strong foundation to understand why safety technology resources are very important to the firm.

In this context, a firm's resources are a very important contributor to excellence in safety. Our model therefore contributes to the literature on safety performance by demonstrating the association between a firm's investment in safety technology resources and firm safety performance. Our model also extends the previous research on safety management by describing ways that the firm can adopt safety technology resources to manage safety.

To the best of our knowledge, this is the first empirical study examining how safety technology resource investment has a positive association with firm safety performance. In addition to finding that safety technology resources has a positive association with firm safety, we find when a firm's top management team is knowledgeable about safety technologies, safety technology resources has a greater effect on safety performance. We also find when a firm has competent IT staff, safety technology resources does have a positive effect on a firm's safety performance. Our results are therefore consistent with previous IT investment and firm performance studies. Our results are also consistent with previous safety management research that shows that a firm's internal resources are important to achieving a superior workplace safety environment. Our findings complement and contribute to the stream of IT and operations management literature examining the impact of IT investment on firm productivity and performance. We further show that the firm's top management team knowledge of safety technology and IT personnel competency do matter when analyzing the relationship between safety technology resources and safety.

Our RBV perspective has provided a theoretical explanation for why safety tangible and intangible resources matter when examining the safety management technology adoption practices. The empirical results demonstrate that the effectiveness of safety technology resource investments is also enhanced by the technical know-how of the firm's top management team and IT staff management knowledge, skills, and abilities.

Although three of our four hypotheses were supported, there was a surprising result. We discovered that a firm's intangible safety technology priority resource does not enhance the effect of safety technology resources on safety performance. One possible explanation to this finding is that the firm's management is having difficulty communicating its message regarding safety as a priority. If the top management team is able to more effectively communicate that safety is a priority in the organization, it is quite possible that this message will turn into actionable use of safety specific technology resources.

This chapter, grounded in resource-based view of the firm, has linked physical safety technology resources to safety performance. We have built a model positing that investment in safety technology resources will likely be associated firm safety performance. Empirical evidence based on the U.S. Motor Carrier Industry does support our model. In conducting this research we have shed light on the nexus between safety technology resources and safety. We hope that this study will spur future research on this emerging and important topic.

Chapter 5: Discussion and Conclusion

Introduction

This dissertation highlights the important role that information technology contributes to safety performance. We have suggested that the firm should investment in information technology resources to facilitate increased safety performance. The three models in this dissertation extend previous research on the role of information technology and firm performance. This dissertation therefore contributes to the burgeoning literature on how firms are increasingly utilizing information technology to facilitated increased safety.

Four Problems That This Dissertation Aims to Solve

This dissertation suggested four solutions to the problems that were identified in Chapter 1. The four problems that were identified include: 1) establishing a theoretical linkage between IT investment resources and safety performance; 2) the theoretical development and empirical testing of a model of IT investment resources and safety performance; 3) the theoretical development and empirical testing of a safety specific model of technology resources and safety performance; and 4) the relationship of safety specific technology management practices to safety performance.

Problems #1 and #2: Establishment of Theoretical Link and Empirical Testing: IT Investment Resources and Safety Performance.

To solve the first two problems, in Chapter 2, "IT Investment and Safety: An Examination of The Impact of Information Technology on Safety Performance in a High Reliability Organization," we established a theoretical link between IT investment and safety performance by adopting the resource-based view. We draw upon the work of Bharadwaj (2000) to examine the unique role that IT resources contribute to safety performance. Through the use of the Bharadwaj (2000) RBV framework, we open-up the IT blackbox of how an HRO's investment in physical IT resources, human IT resources, and growth in IT resources may contribute to HRO safety performance. We tested this theoretical framework through the development of a unique IT investment and safety performance database. Our key findings demonstrate that an HRO's physical information technology resources and human information technology resources do lead to improvements in HRO safety performance. Therefore, we demonstrated that a theoretical and empirical relationship does exist between an HRO's investment in information technology resources and safety performance.

Problem #3: Identification of Best Safety Technology Resource Practices

To solve the third problem, in the chapter entitled, "Technology Adoption Patterns in the U.S. Motor Carrier Industry," we describe the specific types of physical information technology resources that may be used for safety performance purposes.

Additionally, we presented the results of our U.S. Department of Transportation sponsored survey which examined the physical information technology safety resources that are being adopted by the large motor carriers across the United States. Our survey consists of the twenty-six most technological advanced safety technologies that are adopted by leading-edge trucking companies. We find that it is the largest carriers, and carriers that travel along national routes that are adopting these technologically advanced safety devices.

Problem #4: Relationship Between Safety Technology Resources and Safety Management Practices to Safety Performance.

To solve the fourth problem, in the chapter, "Driving for Safety: An Examination of Safety Technology Adoption and Firm Safety Performance in the U.S. Motor Carrier Industry," we draw from the resource-based view to examine how safety specific information technology resources contributes to safety performance. Similar to Chapter 2, we developed our theoretical framework based on the Bharadwaj (2000) resource-based view IT investment model. Our theoretical framework in this essay hypothesized on specific ways that safety technology tangible and safety technology intangible resources may improve firm safety performance. We empirically tested our theoretical model based on an over 50% response rate to our federally-sponsored survey. A key finding in this essay is that tangible and intangible safety technology resources contribute to safety performance.

Future Research

The present dissertation provides significant contributions to the literature, but there are many opportunities for future research. One potential future research investigation would consist of a follow-up survey to the topics discussed in the Chapters 3 and 4. The purpose of the follow-up survey would be to examine the growth patterns in the safety information technology resource investments. Chapter 3 and 4 suggest that the U.S. Motor Carrier Industry is at the early adoption of the innovation curve. Therefore, it would be interesting to examine the characteristics of and changes in adoption rates of these safety technology resources over time. The survey could be distributed to the same set of firms. Additionally, through the use of a follow-up survey, one could look at how the change in investment in safety technologies may be related to safety performance.

A second future research investigation can consist of a survey that would examine some of intermediate (mediating) constructs between safety technology investment and safety performance. For example, safety technology investment may be affecting how the firm is able to monitor, gather, and interpret information and knowledge of how its employees are performing. Through safety technology adoption practices, the firm may actually be turning tacit knowledge into explicit knowledge. It is through this information interpretation process that may enable the firm to become more knowledgeable about how its employee are performing, and thus ultimately affect firm safety performance. In this dissertation study, we have made an assumption that safety technology investment has a direct effect on safety performance.

Perhaps, safety technology adoption is affecting safety performance through some set of currently unknown of intra-organizational or inter-organizational "knowledge-flow" constructs.

A third potential future research investigation involves the conducting a competitive dynamics study. In this study, future research would examine how safety technology adoption may impact the firm's ability to engage in firm moves and counter moves in this hyper-competitive market. Based on models by Ferrier, Smith, and Grimm (1999) and Sambamurthy et al (2003), one could examine how information technology is enabling the firm to become more agile in response to the competitive actions of their rivals.

In conclusion, this dissertation research has shed light on the nexus between IT and safety. We are grateful for the tremendous insight and assistance that many colleagues have provided on this on this emerging and important topic. We hope our work on this topic will spur great improvements in the field of safety management.

Appendix

Safety Technology Survey

Section A: Driver Communication Technologies

No.	What percent of your drivers have or use…	Answer (see note below)
A.1	…cellular telephones (with or without hands-free headsets)?	%
A.2	…computers with satellite connections (always on)?	%
A.3	…computers with wireless capabilities?	%
A.4	…handheld personal digital computers (PDAs) with wireless capabilities (e.g., Palm Pilot)?	%
A.5	… mayday system? *Note: A mayday system alerts the truck's dispatcher that the driver was involved in a crash and details of the incident. It may be initiated manually by the driver or automatically through the use of vehicle sensors.* **Note: If less than 1 percent but greater than 0, write < 1%**	%

Section B: Vehicle Communication Technologies

No.	What percent of your vehicles are configured with…	Answer (see note below)
B.1	…GPS systems? *Note: GPS systems use satellite technology to provide for automatic detection of the vehicle's real-time location.*	%
B.2	…automatic collision notification (ACN) systems? *Note: ACN systems automatically detects & sends crash information instantly to a public safety answering point or to the vehicle's dispatcher.*	%
B.3	…automatic vehicle identification (AVI) system? *Note: AVI's are dedicated short-range radio communication systems. These systems consist of a transponder or RF tag on the vehicle & a stationary reader system* **Note: If less than 1 percent but greater than 0, write < 1%**	%

Section C: Driver Performance Monitoring & Driver Assistance/Regulation Technologies

No.	What percent of your vehicles are configured with…	Answer (see note below)
	Driver Performance Monitoring Technologies	
C.1	… on board closed-circuit television cameras (CCTV)? *Note: On-board cameras record the driver's operating performance.*	%
C.2	…electronic log-books (software) *Note: Electronic log-books: monitor driver performance; automate the drivers' hours-of-service; & present the vehicle performance to inspectors.*	%
C.3	…on-board trip computer? *Note: On-board computer collects data on engine speed (RPM), idle time, & odometer reading.*	%
	Driver Assistance Technologies	
C.4	…rear-vision television cameras?	%
C.5	…real-time traffic & weather notification system (software)? *Note: Provides the driver with changes in road conditions including heavy traffic, dangerous routes, & other hazardous situations.*	%
C.6	…route-guidance (directions) & dispatching systems (software)? *Note: Provides the driver, dispatcher, & authorized third parties with information and directions about travel routes.*	%
C.7	…vision-enhancement technology? *Note: Vision-enhancement technology helps the driver operate the vehicle in poor visibility conditions (such as in foggy conditions or evening hours).*	%
	Driver Regulation Technologies	
C.8	…fatigue management technology? *Note: This technology allows the vehicle's dispatch center to monitor the physical conditions of the driver. Examples of this technology include electro-optical technologies to monitor driver's eye movement; sensors to monitor the driver's heart-beat, etc.*	%
C.9	…vehicle speed regulators? *Note: A technology that automatically regulates a vehicle's speed based on a pre-selected point.* **Note: If less than 1 percent but greater than 0, write < 1%**	%

Section D: Vehicle Performance Technologies

No.	What percent of your vehicles are configured with…	Answer (see note below)
D.1	…systems that enable you to manage the carrying and distribution of HAZMAT cargo? *Note: An example of this technology is a hazardous materials package inspection software program that is used by shippers and carriers to track and monitor hazardous materials.*	%
D.2	…adaptive cruise control? *Note: Adaptive cruise control systems use a radar technology that allows the vehicle to maintain a safe distance between vehicles. If this distance becomes too short, then the vehicle automatically adjusts its speed.*	%
D.3	…obstacle detection systems? *Note: Obstacle detection systems use closed-circuit television, infrared, or low frequency radar detection to alert the driver of a potential crash into an obstacle in the road.*	%
D.4	…lane change or road departure warning systems? *Note: Lane change or road departure warning systems are usually vision-based lane trackers. These systems predict when the driver is in danger of switching the lane or departing the road, & trigger an alarm to warn the driver.*	%
D.5	…vehicle stability systems to prevent rollover crashes? *Note: Through the use of sensors, vehicle stability systems automatically detect when a driver is about to lose control of the vehicle. The vehicle stability systems automatically provides stability by helping the driver stay on the intended course, especially in over-steering and under-steering situations.* **Note: If less than 1 percent but greater than 0, write < 1%**	%

Section E: Vehicle Maintenance Technologies

No.	**What percent of your vehicles are configured with…**	**Answer** (see note below)
E.1	… **real-time communication systems** transmits vehicle performance information from the truck to the company's vehicle dispatcher while the vehicle is **in use**? *Note: Real-time communication systems provides the truck's dispatcher with real-time or near real-time access to data on the vehicle performance. Vehicle performance data includes data on the vehicle's engine, power-train, and antilock braking systems.*	%
E.2	…**under the hood diagnostic tools** such as digital engine analyzers either in real-time or on a scheduled basis? *Note: Digital Engine Analyzer measures DC and AC volts and amps, ohms, temperature (with optional probe), frequency, RPM, dwell, duty cycle, tests diodes and has a continuity beeper.*	%
E.3	…on board electronic vehicle management systems (EVMS)? *Note: On-board EVMS records time and date, distance, speed, idle time, hard accelerations and decelerations, and engine diagnostic trouble codes.*	%
E.4	…**automatic tire pressure gauges** that provides computer read-outs and monitoring capabilities? *Note: A hand-held device that not only shows up the tire pressure on a led screen, but also tells you the pressure through an incorporated sound system.*	%
	Note: If less than 1 percent but greater than 0, write < 1%	

Section F: Future Safety Technology Benefits

DEFINITION: Safety performance benefits: the company's ability to prevent injury to life or damage to property.

Many of the technologies discussed thus far are relatively new and have not been used yet. However, we would like for you to consider the safety performance benefits that you would expect in 5 years – Year 2010 -- from each of these technologies whether or not you have made any investments in these technologies to date.

Specifically, we would like for you to judge the degree to which each of these technologies might benefit your safety performance in Year 2010. We would like for you to make this judgment by distributing 100 points across these technology categories.

Here are some examples to help you answer this question.

Example #1: If you believe that all of the safety performance benefits in Year 2010 will come from vehicle maintenance technologies only, then give this technology category all 100 points.

Example #2: If you believe that you will receive most of safety performance benefits from Vehicle Communication Technologies, some benefits from Driver Communication Technologies, and a few benefits from Vehicle Maintenance Technologies, then you may consider distributing 70 points to Vehicle Communication Technologies, 20 points to Driver Communication Technologies, and lastly 10 points to Vehicle Maintenance Technologies.

	Categories	**Future Safety Benefits (5 years from now)**
F.1	**Driver Communication Technologies**	points
F.2	**Vehicle Communication Technologies**	points
F.3	**Driver Performance Monitoring & Driver Assistance/Regulation Technologies**	points
F.4	**Vehicle Performance Technologies**	points
F.5	**Vehicle Maintenance Technologies**	points
		Total should be 100 points.

SECTION G: Technology Readiness

INSTRUCTIONS: For the following statements, please indicate your level of **disagreement** or **agreement** by circling the number that most closely corresponds to what you believe to be true.

		Extremely Disagree	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree	Extremely Agree
G.1	My company likes the idea of doing business via computers because we are not limited to regular business hours.	1	2	3	4	5	6	7
G.2	My company likes the idea of doing more things now with advanced technology than a couple of years ago.	1	2	3	4	5	6	7
G.3	My company likes the idea of doing business with the newest technologies because they are much more convenient to use.	1	2	3	4	5	6	7
G.4	My company likes computer programs that allows us to tailor things to fit our own needs.	1	2	3	4	5	6	7
G.5	My company is among the first among our competitors to acquire new technologies.	1	2	3	4	5	6	7

	Extremely Disagree	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree	Extremely Agree	
G.6	My company is usually able to figure out how to use new information technology products without the help of external consultants.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
G.7	My company seeks out opportunities to try new information technology solutions.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
G.8	My company's business partners come to us for advice on new technologies.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
G.9	My company believes that new technology is often too complicated to be useful.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
G.10	My company believes that new technology requires paying a lot of money for something that is not worth too much.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
G.11	My company believes that new technology is too overwhelming because you need to know too much to use it.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
G.12	My company does not consider it safe to give out a credit card number over a computer.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
G.13	My company does not consider it safe to do any kind of financial business online.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
G.14	My company is worried that that information that we send over the Internet will be seen by other people.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
G.15	My company does not feel confident doing business with a place that can only be reached online.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

SECTION H: Company Strategy

DEFINITION: Safety performance: the company's ability to prevent injury to life or damage to property.

INSTRUCTIONS: For the following statements, please indicate your level of **disagreement** or **agreement** by circling the number that most closely corresponds to what you believe to be true.

		Extremely Disagree	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree	Extremely Agree
H.1	**Management** clearly considers the safety of employees most important.	1	2	3	4	5	6	7
H.2	**Management** does not cut corners where safety is concerned.	1	2	3	4	5	6	7
H.3	**Management** makes sure that our equipment is in good condition and well taken care of.	1	2	3	4	5	6	7
H.4	**Management** does all it can do to prevent accidents.	1	2	3	4	5	6	7
H.5	**My company** seeks ways to create or strengthen partnerships/alliances with the IT department within my organization.	1	2	3	4	5	6	7
H.6	**My company** seeks ways to support/promote the use of IT in my division.	1	2	3	4	5	6	7
H.7	**My company** seeks ways to encourage my division and the IT department to learn of ways to use IT to solve safety performance issues.	1	2	3	4	5	6	7

	Extremely Disagree	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree	Extremely Agree
H.8	**My company's top management team** is knowledgeable on how to use information technology to improve its safety performance.	1	2	3	4	5	6	7
H.9	**My company's top management team** is knowledgeable about the potential and limitations of current information technology solutions to improve safety performance.	1	2	3	4	5	6	7
H.10	**My company's top management team** is knowledgeable about how our competitors are applying information technology to improve safety performance.	1	2	3	4	5	6	7
H.11	**My company's information technology personnel** have the ability to plan, organize, and lead projects.	1	2	3	4	5	6	7
H.12	**My company's information technology personnel** have the ability to plan and execute work in a collective environment	1	2	3	4	5	6	7
H.13	**My company's information technology personnel** have the ability to work in a project team environment.	1	2	3	4	5	6	7

Section I: Background Information
INSTRUCTION: Please rate your how well informed you are on the following safety technologies.

		NOT AT ALL INFORMED	WEAKLY INFORMED	AVERAGE	INFORMED	WELL INFORMED
I.1	**Driver Communication Technologies**	**1**	**2**	**3**	**4**	**5**
I.2	**Vehicle Communication Technologies**	**1**	**2**	**3**	**4**	**5**
I.3	**Driver Performance Monitoring & Driver Assistance/Regulation Technologies**	**1**	**2**	**3**	**4**	**5**
I.4	**Vehicle Performance Technologies**	**1**	**2**	**3**	**4**	**5**
I.5	**Vehicle Maintenance Technologies**	**1**	**2**	**3**	**4**	**5**

J. Please indicate the approximate total number of employees that work in your company (all locations) by checking the appropriate line: (check one)

J.1	50 or fewer	
J.2	51-100	
J.3	101-500	
J.4	501-1000	
J.5	1001 – 2000	
J.6	2001 or more	

K. Please indicate the approximate total yearly sales for your company (all locations) by checking the appropriate line (check one):

K.1	$10 million or less	
K.2	MORE than $10 million, up to $50 million	
K.3	MORE than $50 million, up to $100 million	
K.4	MORE than $100 million, up to $200 million	
K.5	MORE than $200 million up to 500 million	
K.6	MORE than $500 million, up to $1 billion	
K.7	MORE than $1 billion	

L. Please indicate the geographic scope of your company's operations? (check one)

L.1	Local	
L.2	Regional	
L.3	National	
L.4	Worldwide	

M. Please indicate the type of motor carrier service that you provide. (check one)

M.1	Less than Truck Load (LTL)	
M.2	Truck-load (TL)	
M.3	Both LTL and TL	

Company Strategy

Principal Component Analysis with Varimax Rotation (Company Strategy)					
Item	**Safety As A Priority (α=0.904)**	**Top Management Knowledge of Safety Technology (α=0.953)**	**IT Personnel Competency (α=0.892)**	**Mean**	**Standard Deviation**
Management clearly considers the safety of employees most important.	**0.853**	0.152	0.143	6.1843	0.88403
Management does not cut corners where safety is concerned.	**0.880**	0.187	0.195	5.9169	1.00992
Management makes sure that our equipment is in good condition and well taken care of.	**0.837**	0.147	0.172	5.9873	0.88593
Management does all it can do to prevent accidents.	**0.819**	0.134	0.263	5.8391	1.07189
My company's top management team is knowledgeable on how to use information technology to improve its safety performance.	0.331	0.324	**0.793**	4.8967	1.15759
My company's top management team is knowledgeable about the potential and limitations of current information technology solutions to improve safety performance.	0.273	0.231	**0.868**	4.8489	1.08451
My company's top management team is knowledgeable about how our competitors are applying information technology to improve safety performance.	0.133	0.282	**0.819**	4.6247	1.08912
My company's information technology personnel have the ability to plan, organize, and lead projects.	0.142	**0.889**	0.292	5.0277	1.08647
My company's information technology personnel have the ability to plan and execute work in a collective environment.	0.184	**0.913**	0.265	5.0126	1.07557
My company's information technology personnel have the ability to work in a project team environment.	0.222	**0.897**	0.242	5.1209	1.04742
Eigenvalue	3.180	2.425	2.764		
Percentage of Variance Explained	31.802	24.248	27.644		
Cumulative Percentage of Variance Explained	31.802	56.050	83.694		
Goodness of Fit Tests: Bartlett's Test of Sphericity - Chi-Square = 3581.306, df=45, p <.01; and Kaiser-Meyer-Olkin Measure=0.868					

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