CYBER-PHYSICAL APPLICATIONS FOR FREIGHT TRANSPORTATION SYSTEMS

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16. Abstract

Freight transportation systems constitute key factors in the productivity, environment, and energy consumption in Tennessee, as well as beyond the state’s borders. To achieve more efficient, safe, secure and sustainable transportation, the freight transportation industry is relying heavily on the use of cyber-physical (CP) applications. This involves deploying computing software/hardware to control or monitor physical components in real-time (e.g., automation, sensors, mobile technologies, global positioning systems - GPS). The objectives of this study are threefold, (1) perform a comprehensive review of existing and anticipated CP technologies and applications, with a critical eye on their role in improving freight transportation management and operations, (2) evaluate new technologies according to their performance in achieving system efficiency, safety, security, and sustainability through an online survey of freight operators, and (3) assess the current status and future projection of freight transportation in Tennessee. The results of a survey performed as part of this study show that CP technologies have improved the efficiency of freight operations by reducing delays and providing more reliable information sharing. However, concerns have been expressed as to potential limitations to CP adoption due to issues involving information fidelity, application scalability, and acquisition/operating costs. To further assess the potential impacts of CP technologies in the State of Tennessee, a sustainability assessment of economic, environmental, and social impacts is performed for the trucking mode (the dominant mode of freight transport in Tennessee) using Freight Analysis Framework (FAF) data. The findings from the sustainability assessment show that there can be significant economic, environmental and social benefits from using CP technologies that have been overlooked in past years. Ultimately, the deliverable from this study is this synthesis report summarizing the opportunities and challenges of implementing cyber-physical applications for freight transportation systems management and operations, including recommendations for how TDOT and the freight transportation industry in Tennessee can make the most appropriate use of this growing technology trend.

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LIST OF ABBREVIATIONS

ADTT	Average Daily Truck Traffic
ATRI	American Transportation Research Institute
CAS	Collision Avoidance Systems
CBA	Cost Benefit Analysis
CFS	Commodity Flow Survey
CP	Cyber-Physical
CVISN	Commercial Vehicle Information Systems and Networks
DOT	Department of Transportation
EDI	Electronic Data Interchange
EPA	The Environmental Protection Agency
FAF^4	Freight Analysis Framework, Version 4
FHWA	Federal Highway Administration
FIRST	Freight Information Real-Time System for Transport
IAM	Integrated Assessment Model
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
ISA	Intelligent Speed Adaptation
ISP	Internet Service Provider
GHG	Greenhouse Gas
GPS	Global Positioning System
KTons	Kilotons
LEO	Low Earth Orbit
NPV	Net Present Value
NRC	National Research Council
RFID	Radio Frequency Identification
ROI	Return-on-Investment
$SC\text{-}CO_2$	Social Cost of Carbon
TDOT	Tennessee Department of Transportation
TEF	Truck Equivalency Factor
VBS	Vehicle Booking Systems
VMT	Vehicle Miles Traveled
WIM	Weigh-In-Motion
$K	Thousand US Dollars
$M	Million US Dollars
$B	Billion US Dollars

EXECUTIVE SUMMARY

Freight transportation systems constitute key factors in the productivity, environment, and energy consumption in Tennessee, as well as beyond the state's borders. To achieve more efficient, safe, secure and sustainable transportation, the freight transportation industry is relying heavily on the use of cyber-physical (CP) applications. This involves deploying computing software/hardware to control or monitor physical components in real-time (e.g., automation, sensors, mobile technologies, global positioning systems - GPS). CP technologies present opportunities for freight management and operations in both the public (e.g., ports, traffic operations, incident management) and private (e.g., shippers, carriers, warehouse/distribution operators) sectors. The goal of this study is to evaluate CP technologies in freight transportation systems and assess their direct and indirect implications on operations, the economy, the environment, and the society. Towards this goal, the objectives of this study are threefold and presented below:

- Perform a comprehensive review of existing and anticipated CP technologies and applications, with a critical eye on their role in improving freight transportation management and operations.
- Evaluate new technologies according to their performance in achieving system efficiency, safety, security, and sustainability through an online survey of freight operators
- Assess the current status and future projection of freight transportation in Tennessee.

The results of a survey conducted as part of the study show that CP technologies have improved the efficiency of freight operations by reducing delays and providing more reliable information sharing. However, concerns are expressed on potential limitations to CP adoption due to issues involving information fidelity, application scalability, and acquisition/operating costs. Excessive dependency on CP systems can introduce vulnerability to accidental and intentional security breaches, a growing concern as many freight operators are shying away from investing in these systems.

Further, a sustainability assessment of economic, environmental, and social impacts is performed for the trucking mode (the dominant mode of freight transport in Tennessee) using the Freight Analysis Framework (FAF) data. More specifically, the conversion of FAF commodity flows to truck traffic approach is used to develop three different scenarios for implementation of CP technologies to represent different levels of technology penetration in Tennessee's freight industry. The findings from the sustainability assessment show that there can be significant economic, environmental and social benefits from using CP technologies that have been overlooked in past years. Economic analysis shows that benefits can be as much as 9 times the costs in terms of present values. Social benefits can mount to more than $67M when only 3% of total trucks use smart GPS systems. And environmental benefits of 1% CP technologies penetration in the truck industry are equivalent to GHG emissions savings from 40,849 passenger vehicles driven for one year.

This synthesis report summarizes the findings of the cost-benefit analysis and provides a synthesis of the opportunities and challenges of implementing cyber-physical applications for freight transportation systems management and operations, including recommendations for how

TDOT and the freight transportation industry in Tennessee can make the most appropriate use of this growing technology trend.

1. INTRODUCTION

The freight transportation industry plays a crucial role in societal economic well-being. This industry is facing many new challenges, particularly related to the increase in demand due to urbanization. There is a consensus among policy makers and local authorities that constructing new infrastructure can no longer be the only answer to this issue (Crainic et al., 2009). To improve the efficiency, safety, sustainability and enhance the productivity of freight transportation, private and public fleet operators are taking advantage of new technologies, i.e., Cyber-Physical (CP) systems. These systems are defined as co-engineered interacting networks of physical and computational components. Embedded computers and networks monitor and control the physical processes, with feedback loops where physical processes affect computations. They use close integration and coordination between computation, networks and physical devices that are connected to allow for monitoring and manipulation in the real world. The Federal Highway Administration (FHWA) classifies CP systems into five primary categories, (1) asset tracking, (2) on-board status monitoring, (3) gateway facilitation, (4) freight status information, and (5) network status information (Wolfe and Troup, 2005a).

The main purpose of CP system implementation in freight transportation is to assist in moving a shipment to its destination within a given schedule that minimizes delays en-route. CP systems are also expected to enhance resilience, safety, and security of transportation operations. This study serves as a review of the state of the practice of CP technologies in the freight transportation industry, with a focus on truck transportation. To the best of our knowledge, this is the first study that not only provides a comprehensive literature review on the CP technologies in freight transportation, but also provides the state of the practice of CP technologies among U.S. freight operators using the results of a nationwide survey. While this study focuses on the CP aspects of information technology, intelligent freight technologies currently in place that are required for operation of CP systems are also discussed. A relationship is drawn between CP technologies and the information exchange that is the Internet of Things (IoT). Many methods of data collection and information transfer exist, but the current trend in new technology due to its versatility is the IoT (Hribernik et al., 2010). One example of this relationship is the use of Radio Frequency Identification (RFID) technology in the freight industry. A freight package with an RFID tag can be read by an RFID reader to establish an encounter; this is the extent of the physical technology while the connection to an overarching wireless sensor network takes place in cyberspace (Möller, 2016).

The remainder of this document is organized as follows. Section 2 presents a review of the categorization of different CP technologies, including a summary of current practices, and their impact on various industries. In Section 3, a synthesis of the main technologies that are currently in practice, with a discussion of the trade-offs on costs and benefits of their implementation, is presented. The results of the survey of freight operators are presented and discussed in Section 4. Section 5 to Section 9 present a comprehensive sustainability assessment framework of CP technologies implementation in Tennessee. Finally, in Section 10 the opportunities and challenges of implementing cyber-physical applications for freight transportation systems management and operations, including recommendations for how Tennessee Department of Transportation (TDOT) and the freight transportation industry in Tennessee can make the most appropriate use of this growing technology trend are provided.

2. CATEGORIZATION OF CYBER-PHYSICAL TECHNOLOGIES

In this section, a comprehensive review of CP technologies with their current state of the practice in freight operations is presented. The technologies are classified based on the FHWA categorization of the five CP systems (Wolfe and Troup, 2005b). For each category, a definition is provided along with some examples of different technologies being used and their impacts on the effectiveness of freight operations.

2.1. Asset Tracking

Asset tracking is monitoring the maintenance and status of assets using technologies such as mobile communications, bar codes and RFIDs (Tuttle, 1997). Primarily, assets are defined as tractors, trailers, chassis, containers, and rail cars. Having detailed trailer information, such as location, health and physical condition, can be extremely beneficial in terms of implementing cost-effective strategies. Tracking technologies significantly improve asset management through near real time visibility and status, especially in intermodal arrangements, where a method of communication is required when changing transportation modes (e.g., between waterway, truck, and rail), such that an association is maintained between the container and the chassis.

Tracking technology helps to improve container visibility, which is extremely important for both the shipper and the consignor of the shipment. There are many different practices that are currently in use for asset tracking. Real-time tracking and visibility is made possible by satellite positioning. From a broad perspective, the four segments in tracking of mobile objects are, (1) a spatial component that requires signals from a GPS, (2) a telecommunications segment using mobile phone networks, (3) an application segment that generally uses a secured connection on the web, and (4) a user segment that is the control center (Reclus and Drouard, 2009a). For more sophisticated real-time tracking and higher accuracy, Low Earth Orbit (LEO) satellites can be utilized. Container status is conveyed by an Internet Service Provider (ISP) to notify and transmit information to both the shipper and consignor. The container itself contains an antenna, GPS receiver, data controller, Radio Frequency (RF) module and battery. The RF module conveys the location information to a LEO satellite from which it is then relayed to a control center and finally, through the internet, to the destination - a computer. This technology is important in enhancing visibility as well as saving cost against losses or damages. It also has the potential to impact insurance premiums for shippers. There are two primary reasons for reduced insurance premiums, (1) greater driver accountability, and (2) improved recovery of stolen goods. Telogis, a provider of fleet management software, reports that for fleets utilizing its GPS technologies, Liberty Mutual insurance provides a 25% reduction in insurance rates and AAA insurance by 18% (Ewing, 2017). This shows that the cost of implementing advance technologies can be absorbed by the future savings on insurance premiums.

One proprietary communication system used in asset management is the OmniTRACS system. This is an established technology that has been in use since 1988. OmniTRACS uses Ku-Band satellite communications that provides both position information and reporting to users as well as two-way messaging services (Tiedemann et al., 1990). In addition, fleet broadcasting, call accounting and message confirmation services are provided. The primary advantage of this system is that it uses the prevalent Ku-Band components which telephone, television and private data networks already employ. This saves extensive costs that are required in launching of satellites for freight tracking purposes. With this system, the coverage is not limited solely to metropolitan areas, but reaches rural areas as well, thereby providing coverage for the entire continental United States (Salmasi, 1989).

Another commonly used asset tracking technology is Geofencing. By means of GPS or RFID technologies, a set of geographical coordinates is located to create a virtual boundary in a geographic area. If the container crosses this virtual boundary, an alert is sent to a central command center (Reclus and Drouard, 2009b). In addition to the security benefits, which prevent potential risks (e.g., terrorist attacks to hazardous goods), Geofencing has important applications in logistics and fleet management. Customers at points of interests (e.g., warehouses or customer facilities) can receive alerts when the goods are within proximity. For more than just a broad area in which freight is maintained, Geofencing can also be used for route adherence monitoring, ensuring no deviation occurs of the freight from a pre-specified route. An alert is sent if the object crosses any of the boundaries (Carr and McCullagh, 2014).

2.2. On-board Status Monitoring and Control

On-board status monitoring consists of sensors that are used to monitor vehicle operating parameters, cargo condition and load tampering attempts (Edwards et al., 2005). By monitoring performance and condition of trucks, algorithms are employed to make proper adjustments that help attain higher efficiency. A classic example of on-board status monitoring technology is the telematics device on UPS trucks. The device captures information on more than 200 parameters that include speed, RPM, oil pressure, seat belt use, number of times the truck is placed in reverse, idling time, and so on (Mika, 2010). This allows for both real-time adjustments that the driver can make to improve efficiency as well as performance and condition monitoring that will help to reduce fuel consumption, emissions and maintenance costs, while improving customer service and driver safety.

Many technologies in this category are focused on safety and risk mitigation. Truck collisions in 2013 resulted in an estimated 95,000 injuries and more than 3,960 deaths (Grove et al., 2016). Devices as simple as electronic speed checkers that create an audible or visible alert for the driver when a certain speed is exceeded prove useful in reducing speeding. This reduces accident occurrence rate as well as an improvement in safety operations (Marell and Westin, 1999). More advanced technologies include Collision Avoidance Systems (CAS) that, in passive systems, warn drivers of an impending crash, and in active systems attempt to prevent the crash entirely or mitigate the impacts (Seiler et al., 1998). CAS technologies generally use sensors to detect other vehicles, pedestrians or other objects in surrounding area. The main usage of CAS technology is emergency braking systems that detect an impending collision and apply the brakes without the requirement of driver involvement. Other CAS technologies include collision warning alerts, lane departure warnings and adaptive cruise control (Ervin et al., 2005). Collision warning and lane departure alerts monitor the vehicle's blind spots and its position on the road to prevent a truck from moving into other vehicles (Grove et al., 2016). Adaptive cruise control systems allow for speed to be maintained until a vehicle is detected in front, in which case brakes and engine retardation are applied until the vehicle is outside a given safety threshold distance. Adaptive cruise control helps to not only prevent accidents but also reduces traffic congestion. One study showed that if just 20% of vehicles use adaptive cruise control on a highway, traffic congestion can be eliminated (Davis, 2004).

Other on-board status monitoring devices include temperature sensors that improve the quality of perishable shipments. A common technology used in agricultural shipments is gas sensors for ethylene detection. Ethylene is a direct indicator for stress exposed on a crop (Jedermann et al., 2006). Moreover, pressure and toxicity sensors maintain accountability for hazmat shipments.

In addition to these systems, tamper detection methods have become increasingly important due to increases in valuable freight transportation like biohazards or Weapons of Mass Destruction (WMDs). Basic methods of tamper prevention include an electronic seal by way of a tripwire or magnetic circuit on a container that, if continuity is disabled, can alert the driver or monitoring station through an RFID tag (Tuttle, 1997). While a tripwire would require replacement, a magnetic circuit can be reset as many times as needed. Tamper-indicating devices can also be employed by use of a gas proof seal-barrier. If a single parameter changes, the internal atmosphere condition is affected, this change can be detected and reveal evidence of tampering (Wandel, 2006). In the case of containers with more advanced intrusion detection systems, it is possible to precisely determine whether small changes have occurred in the internal environment. These are referred to as Container and Trailer Security Devices (CSDs and TSDs). One example is the use of an "inside-seal" that requires many communication nodes placed on the walls of a container with specified powered communication with each other. The system is able to detect any type of change, implying that an intrusion has occurred (Hisano and Nakamura, 2002).

2.3. Gateway Facilitation

Gateways are often found as terminal gates, highway inspection stations or border crossings. These are points at which transportation flow rates are reduced and CP technologies can be used to facilitate these transitions. Though often overlooked in infrastructure investments, gateways act as a bottleneck in the efficiency of transportation operations. CP technologies with the goal of gateway facilitation have two primary objectives, (1) increase efficiency of freight flow through gateways, and (2) increase security. Having technologies in place that both improve the performance at gateways while also maintaining security can have tremendous benefits to the freight industry. Examples of technologies in use include RFID, smart cards, weigh-in-motion and nonintrusive inspection technologies (Hernandez et al., 2016).

Driver identification and validation are necessary at freight pickup points, intermediate terminals and destinations. Biometric identification tools such as fingerprint and iris recognition are in place in some companies. As part of the Commercial Vehicle Information Systems and Networks (CVISN), driver credentials are electronically stored with higher quality and accuracy than hand-entered data (Evaluation of the National CVISN Deployment Program, 2005). This database also includes other information related to the carrier such as past inspection results, carrier safety history, law enforcement information, current fuel tax and operating credentials status. This information is useful for detecting which vehicles should be inspected first and how they should be inspected (Brown et al., 2009). As inspections at terminals take significant amounts of time, X-ray or gamma ray scanners can help search containers for contraband in a non-intrusive way (Wolfe and Troup, 2005). While various means of tamper detection are mentioned in the previous section discussing on-board status monitoring, detection can also occur via inspection at gateways. However, inspections are usually randomly assigned, with the possibility of illicit goods being transported without detection. Among all of the incoming freight into the United States (approximately 11 million containers annually), only 3.7% are actually inspected (Hans, 2016). To increase this proportion, in some cases X-rays can be used from outside of the container to detect any dangerous items that might have been illicitly secreted or tampered. In other cases, radiation detectors and odor sensors are used to identify dangerous articles.

In addition to driver identification, vehicle identification and clearance is important for transportation security and law enforcement purposes. Electric screening can occur via use of in-vehicle radio-frequency transponders and roadside readers like EZPass. This technology allows for preclearance of trucks in order to avoid delays due to weigh and inspection stations. EZPass is also popularly used in electronic toll payment which helps avoid delays. In addition, Weigh-In-Motion (WIM) devices prevent backups that are associated with traditional weigh stations. Also, overloaded trucks impose safety risks as well as infrastructure costs. Stopping distances are significantly reduced, increasing the frequency of accidents (Jacob and Feypell-de La Beaumelle, 2010). A study of Interstate truck weigh stations in Illinois showed that using WIM and automatic vehicle identification technologies can reduce accidents by 38 percent (Barnett and Benekohal, 1999). Moreover, pavement and bridges deteriorate much faster when they are more frequently used by trucks that are over the weight limit. A study by the FHWA identified that overloaded trucks cost taxpayers 160-670 million dollars per year for pavement costs (National Research Council, 1990). In 2000, before WIM devices were more widely established, costs to consumers due to stopped trucks were estimated at $15M per day (Davis, 2002).

2.4. Freight Status Information

Knowing the information about freight status is crucial to the carrier, the customer and other stakeholders. Information regarding the status of freight flows can be centrally transmitted for use and storage. Centrally stored data is advantageous for its accessibility and security. Relevant information can be provided for customers via web-based technologies which can be especially important for logistical purposes. GPS products may transmit location and engine condition information to a central location to be used by freight providers. This data can be used for the purpose of creating efficient trip chains without impedances (Board and National Academies of Sciences and Medicine, 2010).

One way to communicate important information on freight status is through the use of Electronic Data Interchange (EDI), which provides a platform to share documents and information in machine-readable formats (Allen et al., 1992). Both suppliers and users of transportation can benefit from the use of EDI, especially in processing documents and information associated with transaction activities. When a purchase order occurs for a transportation service, instead of using a physical invoice, the information is transmitted electronically and tracked by a network system. Shipment notification and post-delivery transactions are handled through the EDI system. This technology has been in use since the mid-1990s and continues to be ubiquitous among shipping, tracking and general freight services. With increasing use of online resources, running on many different platforms, a standard way for communication is needed. Web services software uses XML to facilitate communication between these interfaces (Booth et al., 2004). Replacing the need for EDI and XML systems are web based freight portals that utilize the internet. Web based freight portals have become widely employed in recent years. Carriers and third-party logistics companies offer services such as equipment reservations, rates, shipment status, and pickup information over the web (Wolfe and Troup, 2005). Also, many freight companies offer online tracking services so that customers can track their shipments in the real-time. They also use online tracking with mobile applications to further increase visibility.

The Freight Information Real-Time System for Transport (FIRST) is an online technology utilizing EDI to include status information on freight arrival, chassis location, and container availability (Srour et al., 2003). At intermodal points, where cargo must be transferred from waterway to truck, the FIRST system can help to reduce truck congestion and idling time by improving the efficiency and reducing delays at these bottlenecks ("Freight Information Real-Time System for Transport (FIRST)," 2003). The American Transportation Research Institute (ATRI) estimated the costs to the trucking industry due to bottlenecks on the U.S. National Highway System added over $63.4B in 2015, with gateways representing a significant portion of this cost (Systematics, 2005; Torrey and Ford, 2017).

Generally, freight position in warehouses is more important to carriers than to customers. Warehouses are uniquely positioned as the connection between upstream and downstream processes in freight transportation. Logistics resource management in warehouses attempts to improve the efficiency of operations by reducing slowdowns and human error. One method of warehouse materials management uses RFID technology in which packages are tagged and all shelves contain an RFID reader. When a certain package is needed, it can easily be located in three dimensions using a computer database. Specific information of each freight shipment can be entirely encoded on a label which is affixed to the freight where it can travel from the origin to its destination. The label contains valuable identifying information and can be scanned at any point to retrieve this information. Identifying information includes the point of origin, final destination, shipper, freight classification and special handling instructions (Moir and Vandy, 2017). Other attributes to be stored are the Stock Keeping Unit (SKU) codes for product size, dimension and weight. Logistics resource management is also able to include information related to the number of items in the warehouse, current orders for items placed by customers, and loading and unloading times for different orders (Poon et al., 2009).

2.5. Network Status Information

Within the freight flow, network status information helps to integrate data from cameras and sensors, and uses display technologies to monitor traffic, weather conditions, and incidents. The primary goal of network status information is to employ technologies that reduce congestion by way of collecting and managing network data rather than just building new transportation infrastructure to increase capacity (Crainic et al., 2009). Fukui *et al*. (Fukui et al., 2009) found that with increasing density of traffic, information becomes more useful in manipulation of traffic. The most direct way to prevent congestion is to have real-time visibility of transit hubs and terminals where congestion is more likely to occur. This can be done using web-cameras that monitor busy areas. Users can view the webcam and see live video feeds to determine whether long lines are forming or an incident has occurred leading to backups (Srour et al., 2003). Information collected from these cameras includes locations of roads, status of roads, types of vehicles that are on the road and incidents (Mirzabeiki, 2013). Also, truck drivers use mobile applications regarding traffic and road information. Applications such as Co-Pilot Live Truck provide route information adjusted for traffic congestion as well as truck-legal routes based on truck weight, size, load type, and low-clearance zones. A survey performed by uShip found that 70% of truck drivers use their phones for daily business in 2012 (Jutilla, 2012).

Other congestion reduction technologies include truck appointment systems and vehicle booking systems (VBS), which are utilized to help reduce gate congestion that occurs with constant fluctuation of truck arrivals. Regulating the amount of trucks that arrive at a given terminal throughout the day can reduce waiting time. Longer waiting times reduce driver earnings and cut into profits of freight companies. These systems not only reduce idling time, but also give incentives to freight companies to use them, as there is no guarantee of entrance to the terminal without an appointment. One of the largest service providers for appointment systems is called eModal and is used in 54 terminals nationwide (Huynh et al., 2016). Most appointment systems are web based, and give a specified time window in which a given truck is allowed to enter and pick up or drop off freight. Features other than the appointment window are peak-period appointment fees, flexibility features, process features (container validation) and yard management features. One optimization model developed for truck appointments was found to decrease average truck turnaround time at a terminal from 60.01 minutes to 50.19 minutes (Zhang et al., 2013).

3. TECHNOLOGY ADOPTION: IMPACT AND CHALLENGES

There are many challenges and barriers to investing in CP technologies for freight operations. Table 1 summarizes the major technologies that are currently in practice within each category. While the review presented in this study is not exhaustive as many existing freight CP technologies are proprietary, this summary helps to capture what is used widely in the freight industry and the corresponding impacts.

Once testing is performed on a novel technology, a few trailblazing companies will undergo an initial adoption. If these initial adopters are successful, the technology begins to achieve widespread adoption. For example, J.B. Hunt, the third largest trucking company at $5B in revenues for 2012, launched *J.B. Hunt 360* which is an online freight marketplace ("Top 50 Trucking Companies," 2012). The objective of this technology is to create greater visibility and information of the company's supply chain to customers via use of operating systems and cloud based infrastructure. In addition, it uses artificial intelligence to match freight with available truck capacity (Demery, 2017). Based on the new technology's success, market leaders of large companies are expected to implement a similar technology. While J.B. Hunt 360 is at the forefront of this innovation, investments such as these must be made by a critical mass of the freight industry in order to positively affect the economy.

There are three primary motivators for companies to invest in CP technologies. The pursuit of competitive advantage is the primary reason, in order to increase profitability by capturing a greater market share. Another motivator of businesses is the desire to keep up with direct competitors to inspire customer confidence. Finally, government rules and regulations (i.e., particularly regarding safety and security) drive companies to adapt their technologies for the sake of compliance.

The primary reason for the slow growth of CP technology among freight companies is due to the slim profit margins characteristic of the trucking industry. At 1.99% net profit margin for trucking industry in 2018, this is well below the 7.90% total market average of other industries and even bellower than the transportation net profit margin which is 4.44% (Damodaran, 2018). Furthermore, this percentage is from the top 50 companies in terms of revenues, and does not reflect the slimmer margins of regional carriers. This is a particular challenge for small freight companies who have to offer lower prices to compete with larger and more established enterprises. In addition, the industry has very low barriers to entry. This leads to a lot of competition arising from new entrants into the industry (Damodaran, 2018).

Table 1. Summary of primary CP technologies currently in practice

Asset Tracking	**On-Board Status Monitoring**	**Gateway Facilitation**	**Freight Status Information**	**Network Status Information**
satellite positioning	sensors recording vehicle operating parameters	EZ-Pass	web portals	traffic information
RFID container tagging	tamper detection	Weigh-In-Motion (WIM)	Electronic Data Interchange (EDI)	terminal web-cameras
X-ray and non-intrusive inspection technologies	crash detection/avoidance systems	database for driver ID/validation	RFID package tracking for warehouse management	truck appointment systems/VBS
barcodes				mobile applications

Cybersecurity risks associated with CP technologies constitute another significant concern within the industry. Traditional safety measures are unable to provide sufficient protection against the additional risks that are introduced with the implementation of CP technologies. New methods of theft, hijacking, and destruction of property are propagated every day in addition to an increase in the vulnerability to data breaches. A research study by the National Research Council (NRC) found that a major reason for this increased risk is the current freight transportation system environment, which is a coalition of company-to-company information systems that permit efficient operation. However, the design of this system is not well structured and tested. As a result, security design and testing becomes challenging. Cybersecurity risks in freight transportation can have significant impacts that reach far beyond the industry itself and its customers, extending to threats to national security and global economies (Zhang et al., 2011).

While employing CP technologies within freight systems can result in benefits that result in more efficient operations (e.g., reducing transit time, avoiding bottlenecks, and sharing valuable information), they often come at an increased cost of implementation and maintenance. As discussed earlier, insurance premiums can drop as a result of utilizing GPS technologies, however, the question remains as to what happens to those premiums when new types of threats are introduced as a result of this technology.

4. SURVEY AND DATA ANALYSIS

4.1. Profitability

In order to determine the state of the practice and measure the extent to which CP technologies are implemented within the freight industry, a survey was distributed to freight operators in the United States holding a registration with the U.S. Department of Transportation (Appendix 1). Of these, 545 responses were received, providing the ability to characterize the current status of CP technologies across the U.S. freight transportation industry. Among the respondents, 6.4 percent (35 responses out of 545) noted that they have a primary location/terminal in the State of Tennessee.

The size of freight companies in the survey sample spanned a wide range of annual revenues from less than $500k to over $1B; these were then categorized into six groups, as shown in Figure 1.

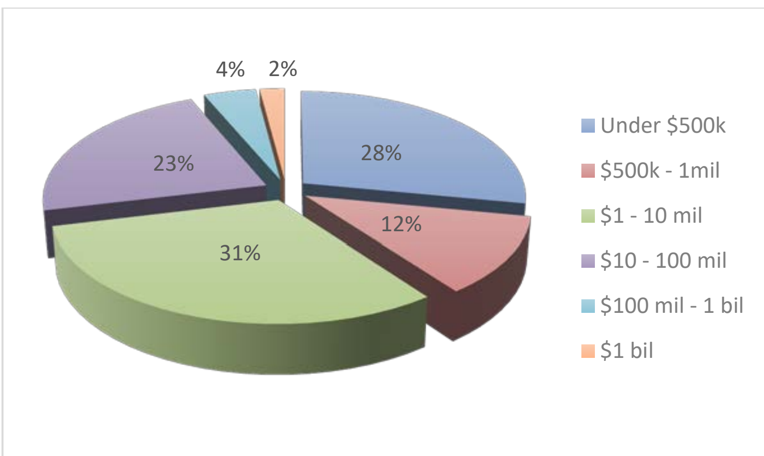


Figure 1. Distribution of survey participants according to the size of the company

According to the survey results, fewer than 50% of companies with less than $100M in revenues are employing CP technologies. By contrast, roughly 70% of the larger companies (i.e., $100M in revenues) are using CP technologies in their freight transportation systems (Figure 2). This percentage increases to over 80% for the largest companies with more than $1B in revenues.

From the five FHWA CP technology categories, the span of technologies employed according the size of the company is quantified. To do so, according to the results of the survey, the average number of different CP technologies (i.e., which is between 0 and 5) for each group of freight operators was determined. It was found that the breadth of technologies covered increased sharply with size of the company, Figure 3. Companies with revenues over $100M used at least one type of CP technology, whereas companies in the range of $1M -10M in annual revenues used, on average, only 0.68 out of 5 technologies. Companies with more than $1B in revenues used, on average, 2.73 out of 5 technologies.

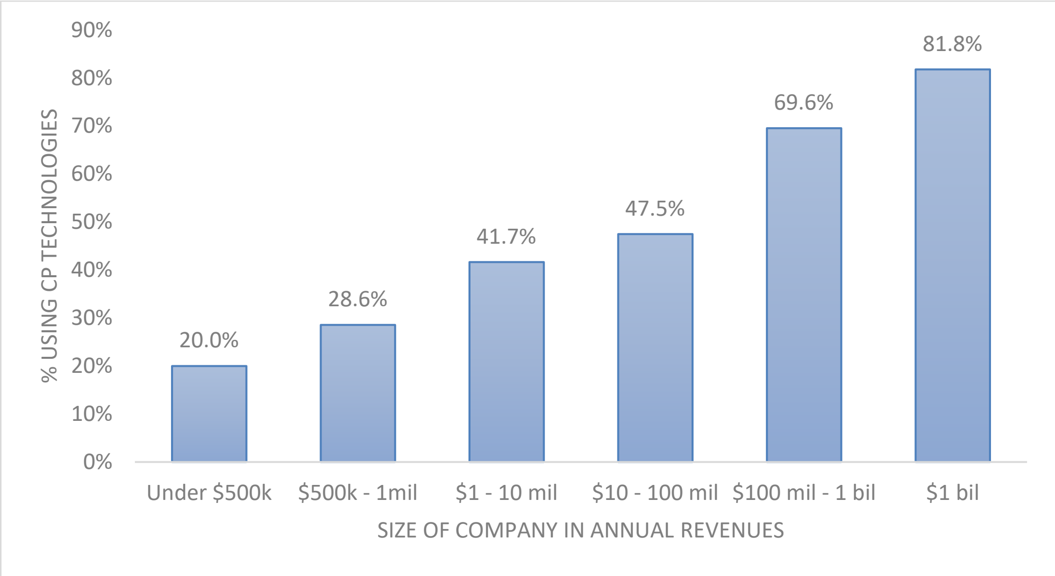


Figure 2. Percentage of companies using CP technologies as a function of annual revenues

In addition, 70% of CP technologies users claim that the benefits of these technologies outweigh the costs of implementation. However, of these companies, only 30% noticed an immediate increase in profitability, which could point to the case of either (i) time for adequate return on investment can be very long, or (ii) that benefits come in the form of increased reliability, safety and security of operations.

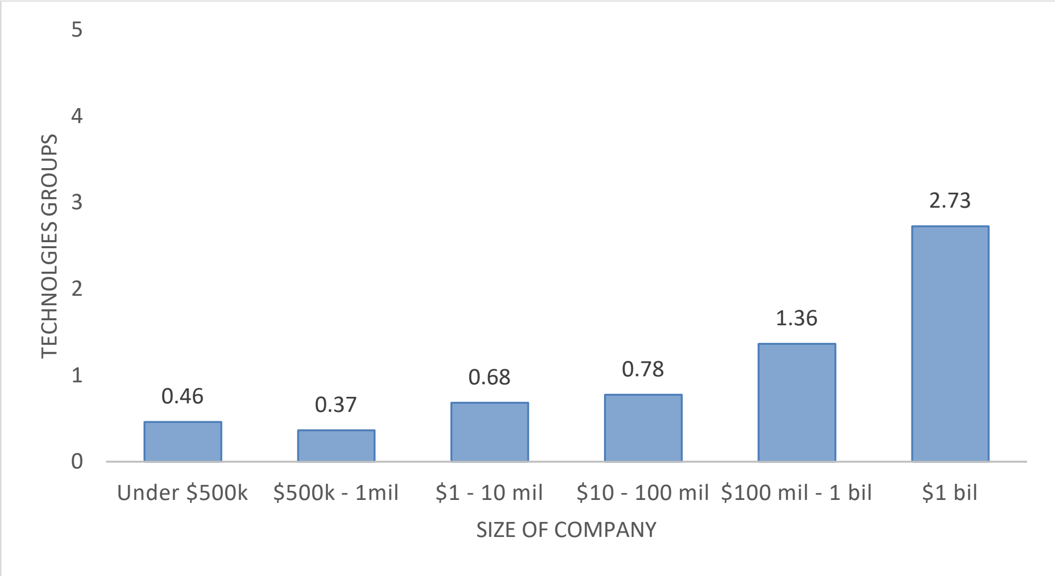


Figure 3. Breadth of FHWA categories covered by companies

4.2. Benefits, Challenges and Concerns

For companies that believe the benefits gained from investments in CP technologies outweigh the costs, the reasons mentioned in the survey are described below.

- *Driver related issues*: New technologies have improved driver satisfaction and safety. One company mentioned that they have calculated the return-on-investment (ROI) for employer satisfaction in their economic analysis and the investment had significant positive impact on profitability. Moreover, freight operators can monitor driver performance and detect improper driver behavior such as excessive idling, speeding and other violations which typically result in vehicle incidents. This has caused less time spent contacting individual drivers via phone. In one example, CP technologies has helped a trucking company to lower the overtime for 30 drivers by 200 hours a month. The reason was that drivers were on a time clock before CP technology implementation and the company could not monitor them all day. In another case, adding forward facing cameras has helped the company to correct driver behavior, resulting in fewer incidents.
- *Customer related issues*: CP technologies have improved customer satisfaction on service. Real-time tracking of freight has increased the reliability and keeps the customers happy.
- *Streamline operations, less paperwork and errors*: This has caused more peace of mind for freight operators. One freight operator mentioned that their trucks have been wrongly identified for causing property damage when their vehicles were not even at the location. Using new CP technologies, they have been able to identify inaccurate customer complaints (e.g., speeding which did not occur due to tracking truck speed devices).
- *Network status information benefits*: The new systems improve route efficiency (i.e., selecting shortest vs. quickest). They improve the ability to avoid congestion and enable better route selection to avoid extreme weather conditions, leading to a reduction in accidents. In addition, real-time maintenance response has been expedited.
- *Fleet management benefits*: Hours of service is a critical point in freight operation. The cost of having trucks that are not moving is very high.
- *Price of the assets*: Transportation assets (i.e., trucks, trailers, tractors and etc.) are expensive. The freight operators mentioned that they cannot afford to lose them. Therefor they prefer to spend money on purchasing devices that can track their assets in real-time.
- *Low maintenance cost of CP technologies*: The annual cost of CP technologies are substantially less than the replacement of one asset.
- *Market competition*: Having the most technological advances makes a freight operator uniquely marketable and can ease beneficial transactions of services.

With the exception of companies in the range of $100M - $1B in annual revenues, the percentage of companies that reported an increase in profitability after employing CP technologies increased with the size of the company (Figure 4). More than 55% of companies over $1B reported an increase in profitability while only 23% of companies under $500,000 reported an increase in profitability. However, over 90% of these companies reported that the significance of this increase in profitability is less than 20%. In fact, profitability or return on investment constitutes the second major concern after CP technology implementation cost that could drive companies away from CP technologies (Figure 5).

Another outcome of the survey is that freight operators do not believe that the risks associated with CP technology implementation are as important as other challenges like such as cost of implementation, return on investment, and reliability. Only 10% of the freight operators mention risk as one of the challenges.

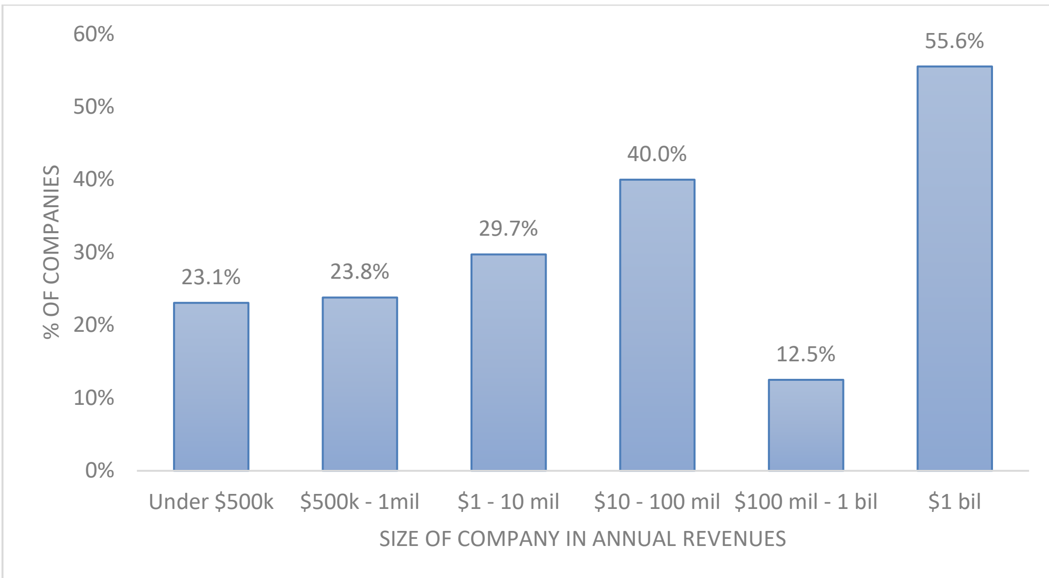


Figure 4. Percentage of companies that report an increase in profitability after employing CP technologies

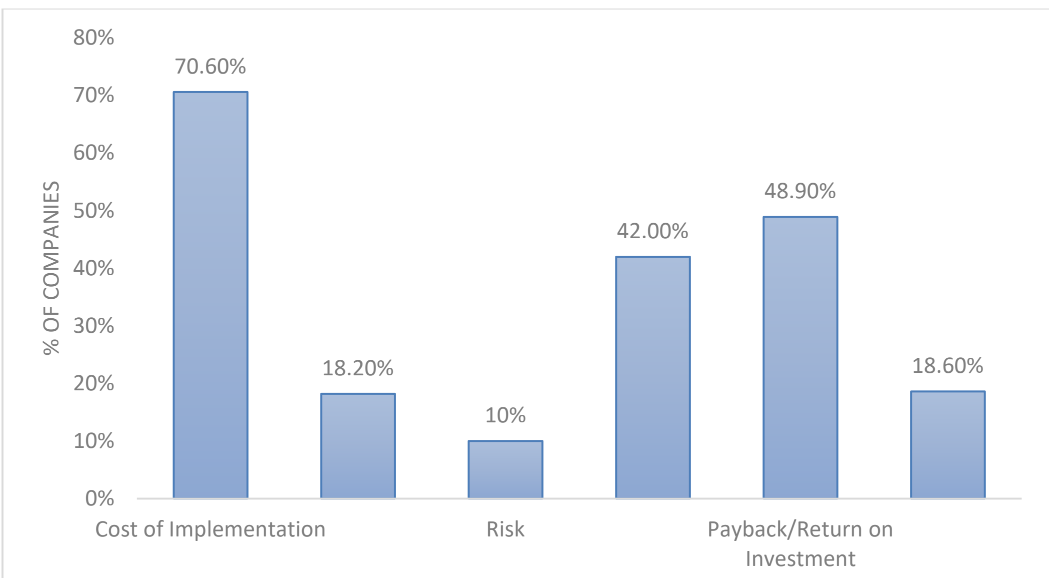


Figure 5. Challenges that freight operators face in the implementation of CP technologies

Within each of the FHWA categories of CP systems, certain technologies were found to be more popular than others. Table 2 shows the distribution of technologies within each category. For instance, GPS systems are the most common technology in asset tracking for both trailers and power units. Earlier studies identify emerging technologies in hazardous materials transportation and corresponding evolvement of CP technologies (Tate and Abkowitz, 2012). A list of near-term and long-term technologies as well as emerging technologies for the future was developed. In that study, technology developers were interviewed (e.g., companies, universities, national labs, etc.) and 23 technology products were identified and categorized in 9 technology areas along with their relative maturity in terms of developmental timeframe (Table 3). An assessment of the development level for the emerging technology areas was also provided in that study (Table 4). The length of the bar in Table 4 shows the relative maturity of each technology in 2012, the year that this study was conducted by interpolating the results of different interviews (i.e., dark blue: the level that majority of development has progressed, light blue: advance entries approaching or having reached the marketplace).

Table 2. Most and least common CP technologies in each group

FHWA Categorization	**Most Common**	**Least Common**
Asset Tracking of Trailers	GPS systems	Autonomous Trucking
Asset Tracking of Power Unit	GPS systems	RFID
On Board Status Monitoring	Vehicle Operating Parameters	Remote Locking & Unlocking
Gateway Facilitation	Weigh-in-motion	Smart Cards
Network Status Information	Congestion Alerts and Avoidance	Online Carrier Scheduling Support

By comparing the results of the study from Tate and Abkowitz (2012), with the outcomes of the aforementioned freight operator survey, it is possible to provide an update on some of these technologies. For example, ″Networked RFID/ubiquitous sensors & cargo monitoring″ has completed its technological development in year 2018, and many companies are using different kinds of GPS systems for their assets and power unit tracking. Remote locking and unlocking systems are today's least common technology for on-board status monitoring. This is potentially due to the fact that ″Advanced locks & seals″ have not completely reached the full development level to be easily used for commercial purposes (Table 2 and Table 4).

In addition to the development process of emerging technologies, there are several other reasons why freight operators might be wary of future investments in CP technologies. The majority of companies are not only concerned with the cost of implementation, rather the reliability of a new technology can present a significant hurdle. In fact, 70% of companies using CP technologies cited cost to be a major issue of implementation while 42% had issues with reliability (Figure 5). Also, many small companies mentioned that they are still on the steep side of the learning curve for training managers and staff, since they are dealing with an aging workforce. They believe that GPS monitoring and vehicle data will pay for itself, however the new Electronic Logging Device (ELD) technology was made mandatory by Department of Transportation (DOT) regulations. Other concerns include errors incurred using CP Technologies which can cost valuable time lost in a competitive drive time environment.

Freight operators identify a few major concerns they have with CP technologies, those are mostly related to investment cost, risk of the technologies being outdated too fast, data breach and privacy issues. The concern with investments is related to profitability in the short term, where the payback time may be long, and in the long term, where the technology may be quickly outdated due to the rapid pace of an evolving industry, requiring further investments. The concern with risk is associated with increased vulnerability and privacy issues. In fact, 30% of respondents cite data breaches, increased vulnerability, or privacy issues to be a significant concern for them.

Table 3. Technology maturity comparison

Technology	**Short term**	**2-5 Years**	**6-10 Years**	**Categories Total**
Networked RFID/ubiquitous sensors & cargo monitoring	3	2		5
Pressure gauges & chemical detection sensors	2		3	5
Fiber-optic/photonic sensors & optical scanners			1	1
Advanced locks & seals	1	1		2
Intelligent video tracking & surveillance	1	1		2
Wireless power	2			2
Nanopiezoelectronics		1		1
Plastic thin-film organic solar cells	1	2		3
Container integrity	1		1	2
Numbers of technology interviews	11	7	5	**23**

Despite all of the concerns that freight operators mention, 43% of overall survey respondents envision making future investments in CP technologies, with the majority of these investments in the categories of asset tracking, on-board status monitoring, as well as freight status information.

However, the majority of these companies are large (more than $100M in revenues), while only 29% of companies under $500,000 envision making future investments in CP technologies (Figure 6). Since freight operators are in the business of moving commodities, reducing costs and improving efficiency in this area is likely a primary goal of any freight company.

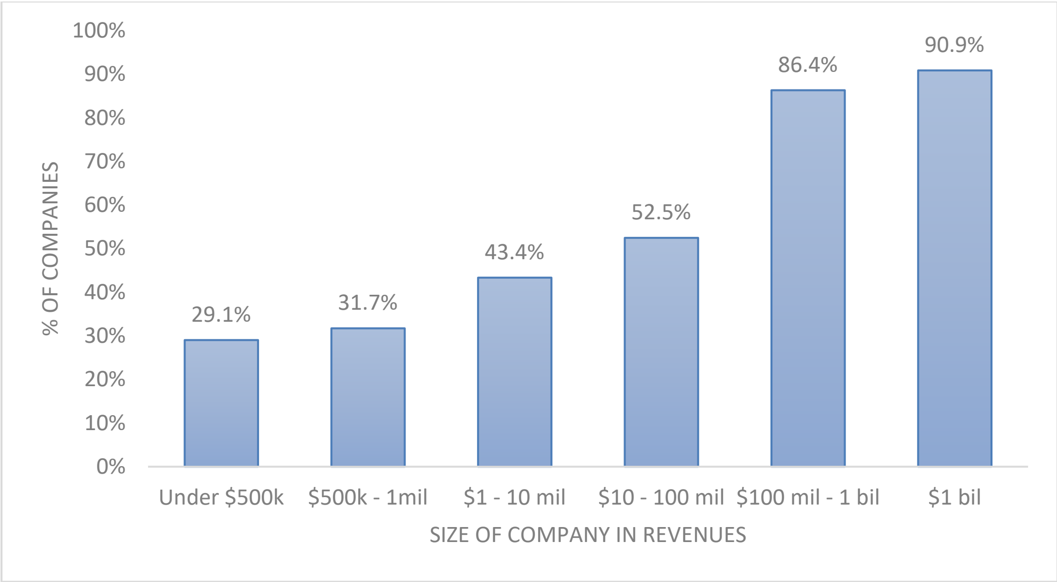


Figure 6. Percentage of companies that envision future investments in CP technologies

Table 4. Development status of most promising emerging technologies

Technology Development level	1. Basic technology principles observed	2. Equipment and process concept formulated	3. Prototype demonstrated in laboratory environment	4. Product operational in limited real-world environment	5. Product available for commercial use
Networked RFID/ubiquitous sensors & cargo monitoring					
Pressure gauges & chemical detection sensors					
Fiber-optic/photonic sensors & optical scanners					
Advanced locks & seals					
Intelligent video tracking & surveillance					
Wireless power					
Nanopiezoelectronics					
Plastic thin-film organic solar cells					
Container integrity					

5. FREIGHT TRANSPORTATION SUSTAINABILITY ASSESSMENT

To assist in describing the costs and benefits related to new investments in CP technologies, an in-depth analysis of the sustainability of freight transport in the State of Tennessee was undertaken. For several decades, the concept of Sustainability has been around and changed the way of thinking of human beings to become more prudent about the impact of their everyday behavior on their surroundings on a local and global scale. Sustainability has three main dimensions, 1) economic growth, 2) environmental protection for now and future generations, and 3) social equity (Behrends et al., 2008).

Freight transportation systems are complex systems that can contribute to economic growth, environmental wellness and social equity (Table 5) (Anderson et al., 2005). Many believe, however, that the current urban freight transportation system due to its significant intrusion in different aspects of human's life is not sustainable (Quak and De Koster, 2006). A sustainable freight transportation can improve the quality of life of city dwellers; reduce global warming and the rate of energy demand; lower air and noise pollution; reduce congestion; and decrease injuries and deaths resulting from traffic accidents (Behrends et al., 2008). Understanding the scope of potential adverse impacts in each category can help achieve sustainability goals. With the growing rate of urbanization, the freight transportation industry is facing new challenges to respond to increased projected demand.

In order to assess the prospects of CP technologies in the State of Tennessee, the current and future state of freight transportation is presented to point out the scope of this industry at the state level (Figure 1). The Freight Analysis Framework (FAF) database provides an estimation of freight transportation to (imports), from (exports), and within (domestic) the United States. FAF is a comprehensive database from which to study the growing demand in the freight industry.

Table 5. Freight transportation sustainability impacts (Anderson et al., 2005)

Economic Impacts	**Environmental Impacts**	**Social Impacts**
Congestion	GHG and pollutant emissions	Public health physical consequences
Inefficiency	Use of non-renewable fossil–fuel and land	Injuries and death resulting from traffic accidents
Resource waste	Waste products	Noise
	Loss of wildlife habitats and associated threat to wild species	Visual intrusion
		Quality of life issues

In the second step, FAF Truck data – which is the dominant mode of freight transportation in Tennessee – is used to perform a sustainability assessment for the impacts of CP technologies on freight networks according to the three main pillars of sustainability, economic, environmental, and social (Figure 7). More specifically, the FAF database is used to determine the amount of annual truck traffic for the entire State of Tennessee. This data is used to develop three different scenarios of CP technology implementation. These scenarios present the level of penetration of CP technologies in freight industry of Tennessee. For each of these scenarios the economic impacts of new CP technologies are calculated using the Net Present Value (NPV) approach. This approach can be utilized to measure the economic profitability of freight CP technologies in Tennessee.

In the third step, the environmental impacts from the reduction in fuel consumption of trucks are estimated and translated to more tangible terms using EPA's Greenhouse Gas Equivalencies Calculator. A comparison of environmental benefits between different scenarios is presented. And finally, in the last step, the social cost of carbon (SC-CO_2) approach is used to monetize climate damages (in this study avoided damages) from GHG emissions, specifically CO_2 emissions, and quantify the social impacts of CP technologies in Tennessee.

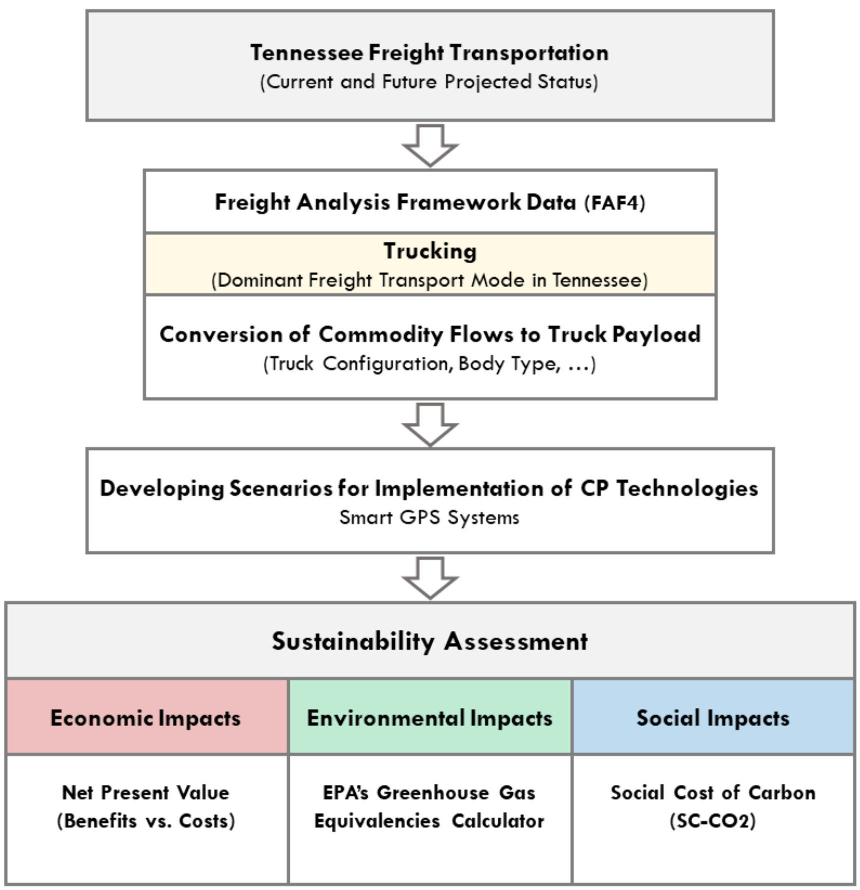


Figure 7. Schematic view of sustainability assessment of CP technologies in Tennessee

6. FREIGHT ANALYSIS FRAMEWORK (FAF)

The Freight Analysis Framework (FAF) was developed through a partnership between the Federal Highway Administration FHWA and U.S. Department of Transportation (DOT) in 2002. Different datasets are integrated to produce a comprehensive database for freight movement inside and outside states for all types of transportation modes. Many updates have been made to this database since its first release, with the latest available version being FAF4. and This database uses the 2012 Commodity Flow Survey (CFS) and estimates of the dollar value (in million dollars - M$) and tonnage (in thousand tons - KT) of freight shipments across 132 FAF zones within the U.S. and eight different international regions for different types of commodity (43 groups of commodity) and mode of transportation (i.e., 7 modes: air (include truck-air), multiple modes & mail, pipeline, rail, truck, water, other and unknown). The database also provides projections of commodity flow changes up to the year 2045, with 2012 being a reference point. Transportation researchers and planners have used this database for various analyses, such as freight policy analysis, truck characteristic studies (i.e., numbers, size, and weight), and highway capacity assessments, among others.

6.1. Tennessee FAF Data and Freight Trends

In order to assess the impacts of CP technologies on freight systems in Tennessee, the FAF database is filtered to identify freight flow through the state. There are four FAF zones in Tennessee, 1) Knoxville - zone ID 314, 2) Memphis - zone ID 368, 3) Nashville - zone ID 400 and 4) the remainder of Tennessee - zone ID 99999 (Figure 8). According to Table 6 and Table 7, there are three types of distribution for commodity flows from Tennessee, 1) within the state, 2) outbound flows, and 3) inbound flows for domestic flows. Truck is the major mode of freight transportation in Tennessee (e.g., 65 and 74 percent of commodity flows for years 2012 and 2045).

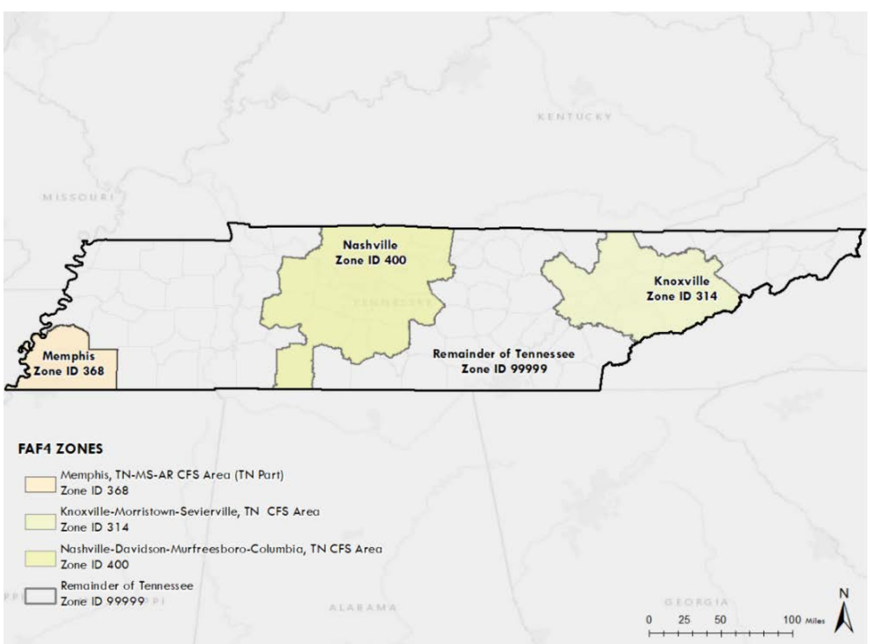


Figure 8. Tennessee FAF zones

Table 6 and Table 7 show that total commodity flow will grow by more than 130 percent between 2012 and 2045 for all types of transportation modes. The share of using truck transportation will significantly increase (by almost by 10 percent). The main takeaways from these two tables on the future of freight transportation in Tennessee are listed below.

- There will be a significant shift for increased usage of trucks in the freight industry.
- Pipeline commodity flow will no longer be the second most heavily used mode of transportation and is going to have a significant drop from 20 percent to 4 percent.
- Intermodal movements (commodities that move by more than one mode like containerized cargo that moves between different modes of transportation) and mail (commodities that shippers who use parcel delivery services typically do not know what modes were involved after the shipment was picked up) will be the next popular modes after exclusive truck transport in year 2045 with more than 16 percent of share in both outbound and inbound commodity flows.
- There will be a decrease in use of rail and water as a mode for freight transportation by year 2045.

Table 6. Shipments within, outbound, and inbound Tennessee – Weight for domestic flows for transportation Mode: 2012

Transportation Mode	Within the given state (O to O)		Outbound from the given state (O to all other states)		Inbound to the given state (all other states to O)	
	Weight (KT)	Percent	Weight (KT)	Percent	Weight (KT)	Percent
Air (include truck-air)	0.4	<0.01	24.5	<0.1	46.9	<0.1
Multiple modes & mail	1,055.3	<1	4,375.1	3	5,658.7	4
Other and unknown	0.0	0	0.0	0	0.0	0
Pipeline	242.9	<1	37,228.6	31	42,603.8	32
Rail	2,149.2	2	8,015.4	7	20,474.1	15
Truck	**127,889.2**	**97**	**68,501.3**	**57**	**56,366.5**	**42**
Water	588.0	0	2,126.4	2	7,538.2	6

According to FHWA, trucks move 66 percent of the U.S. freight by weight (Worth et al., 2016). The findings suggests that there will be even more truck commodity flows in next decades for Tennessee (i.e., 74 percent of share). As such, local authorities need to carefully assess policy making and legislation for truck transportation. Although some public or private sector organizations may collect and manage freight data, there is no consolidated database for the U.S. on the number of trucks passing between each pair of origin and destinations. The 2012 CFS which is embedded in FAF4 provides the volume and value of all commodities between pairs of origin and destination at the national level. This information can then be converted into the number of trucks passing through each pair. Using this conversion, it is possible to develop different sustainability scenarios of different CP technology integration in middle Tennessee.

Table 7. Shipments within, outbound, and inbound Tennessee – Weight for domestic flows for transportation Mode: 2045

Transportation Mode	Within the given state (O to O)		Outbound from the given state (O to all other states)		Inbound to the given state (all other states to O)	
	Weight (KT)	Percent	Weight (KT)	Percent	Weight (KT)	Percent
Air (include truck-air)	51.5	<0.001	5,735.0	1.5	15,862.6	5
Multiple modes & mail	10,711.7	7	62,277.5	16	62,742.1	17
Other and unknown	0.0	0	0.0	0	0.0	0
Pipeline	42.9	<0.001	22,444.0	6	16,125.8	4
Rail	1,683.1	1	5,959.3	2	13,955.6	4
Truck	**137,634.3**	**91**	**276,096.1**	**74**	**243,975.9**	**68**
Water	1,440.2	1	742.0	<1	8,510.3	2

6.2. Conversion of Commodity Flows to Truck Traffic Approach

As mentioned earlier, "*FAF*[4] *Freight Traffic Assignment*" is a report developed by Oak Ridge National Laboratory (ORNL) in 2016. The third chapter in this report introduces a step by step method to convert FAF data to an estimation of the Average Daily Truck Traffic (ADTT) between the FAF shipping zones (Maks Inc., 2016). Figure 9 depicts a flowchart of the step by step method for commodity-to-truck conversion process.

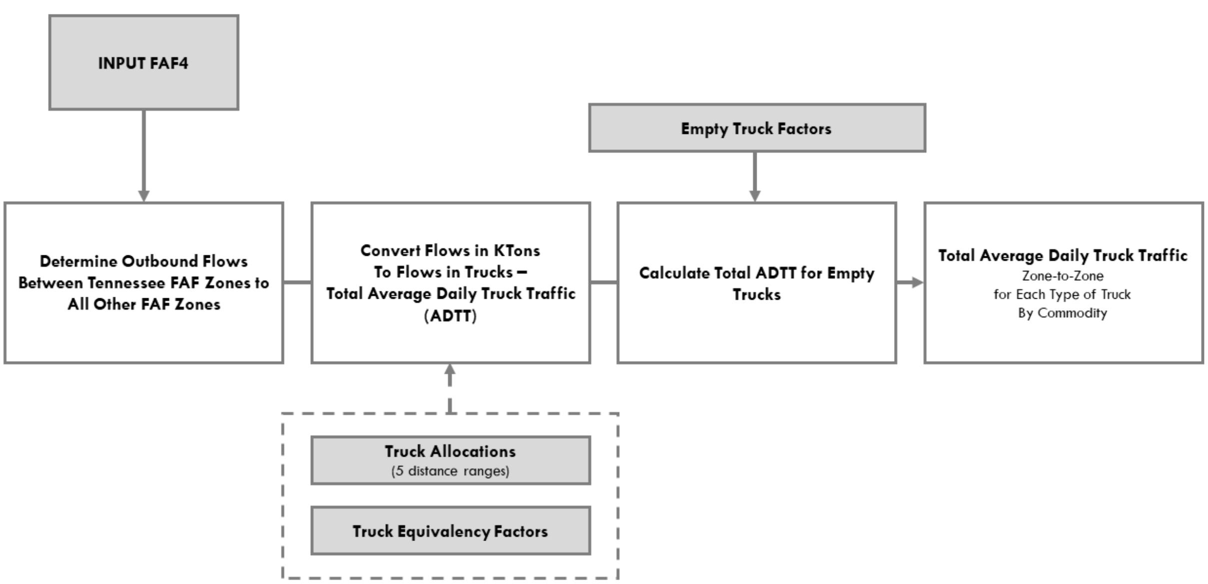
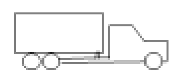
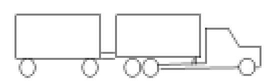
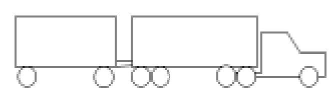
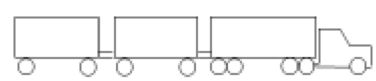


Figure 9. Flowchart of the steps in truck conversion process

The origins and the destinations are first determined to measure the truck traffic between them. The main focus on this study is on the domestic flow of all type of commodities from each FAF zones within Tennessee to all other FAF zones inside the U.S. (flows between FAF zones inside Tennessee are included). The main reason for the choice of these types of flows is the fact that Tennessee authorities can control and manage within state and outbound flows. The second step in the process is to identify the characteristics of trucks (such as truck configuration and body type).

Table 8 shows the five categories for primary truck configuration according to the ORNL report. This is based on the number of trailers and how truck weight is distributed over axles. These trucks have nine different body types: 1) Dry Van (37.72%), 2) Flat Bed (24.37%), 3) Bulk (14.73%), 4) Reefer (8.15%), 5) Tank (7.97%), 6) Logging (2.12%), 7) Livestock (1.7%), 8) Automobile (0.91%) and 9) Other (2.33%). These body types represent the common truck body types operating on the U.S. highways.

Table 8. Truck configuration

Truck Group	Description	Abbreviation	Illustrative Example
1	Single Unit Trucks	SU	
2	Truck plus Trailer Combinations	TT	
3	Tractor plus Semitrailer Combinations	CS	
4	Tractor plus Double Trailer Combinations	DBL	
5	Tractor plus Triple Trailer Combinations	TPT	

Next, the FAF origin-destination tonnages of commodities to different types of the truck configurations are allocated; this corresponds to the second step in the flowchart, Figure 9. There are five distance ranges for the trip lengths that will ensure that the correct tonnage of commodities is assigned to the exact type of truck configuration. Table 9 presents these trip distance ranges with their corresponding allocation factors for each type of truck.

Table 9. Truck distance ranges and allocation factors

Min Range (miles)	Max Range (miles)	Single Unit	Truck Trailer	Combination Semitrailer	Combination Double	Combination Triple
0	50	0.793201	0.070139	0.130465	0.006179	0.0000167
51	100	0.577445	0.058172	0.344653	0.019608	0
101	200	0.313468	0.045762	0.565269	0.074434	0.000452
201	500	0.142467	0.027288	0.751628	0.075218	0.002031
501	10000	0.06466	0.0149	0.879727	0.034143	0.004225

The average payload for each truck is then estimated according to its own characteristics (i.e., vehicle group and body type). The estimation of average payload is implemented in two main steps. First, the mean payloads are established by truck characteristics (truck configuration and body type) and commodity type (Alam and Rajamanickam, 2007). Second, the mean payloads are applied to the allocation percentage by body type to obtain the number of trucks. The parameters and variables used in the process of translating commodity volumes to number of trucks are summarized in Table 10.

Table 10. Conversion factor equation symbols

Symbol	Definition
i	Commodity index (1, 2, … 43)
j	Truck configuration group index (1, 2, … 5)
k	Truck body-type index (1, 2, … 9)
X_i	Tonnage of commodity (i)
Y_j	Number of trucks in truck configuration group (j)
β_{ijk}	Fraction of commodity (i) moved by truck type (j) with body type (k)
ω_{ijk}	Mean payload of truck type j with body type k transporting commodity i
$X_i \beta_{ijk}$	The tonnage of commodity (X_i) carried by truck type (j) and body type (k)
$X_i \beta_{ijk} / \omega_{ijk}$	Number of trucks of type (j) and body type (k) required to move (Xi β_{ijk}) tons

Equation 1 calculates the number of trucks of type ($Y_j=1$) utilized to transfer (X_i β_{ijk}) tons of commodity (X_i) by all body types. With the same approach, this number for trucks of type ($Y_j=2$) is calculated using Equation 2. Using Equation 3, the number of trucks of type (Y_j) used to move (X_i β_{ijk}) tons of commodity (X_i) by all body types is calculated. In the last step, the sum of all commodities on total number of trucks assigned to convert commodity (X_i) is calculated to get the total number of trucks with Equation 4 and Equation 5. From this approach, a new factor is defined named Truck Equivalency Factor (TEF) (Equation 6).

$$Y_{j=1} = \frac{X_i\beta_{i11}}{\omega_{i11}} + \frac{X_i\beta_{i12}}{\omega_{i12}} + \cdots = \sum_{k=1}^{k=9}\frac{X_i\beta_{i1k}}{\omega_{i1k}} \quad (1)$$

$$Y_{j=2} = \frac{X_i\beta_{i21}}{\omega_{i21}} + \frac{X_i\beta_{i22}}{\omega_{i22}} + \cdots = \sum_{k=1}^{k=9}\frac{X_i\beta_{i2k}}{\omega_{i2k}} \quad (2)$$

$$Y_j = \sum_{k=1}^{k=9}\frac{X_i\beta_{ijk}}{\omega_{ijk}} = X_i \sum_{k=1}^{k=9}\frac{\beta_{ijk}}{\omega_{ijk}} \quad (3)$$

$$\sum_{j=1}^{j=5} Y_j = X_i \sum_{j=1}^{j=5}\sum_{k=1}^{k=9}\frac{\beta_{ijk}}{\omega_{ijk}} \quad (4)$$

$$Total\ Trucks\ for\ All\ Commodities: \sum_{i=1}^{i=43} X_i \sum_{j=1}^{j=5}\sum_{k=1}^{k=9}\frac{\beta_{ijk}}{\omega_{ijk}} \quad (5)$$

$$TEF_{ijk} = \frac{\beta_{ijk}}{\omega_{ijk}} \quad (6)$$

The Truck Equivalency Factor, a three-dimensional factor which is a function of truck configuration, body type, and type of commodity, converts tonnage of commodity flows into number of trucks. A comprehensive list of FAF commodity categories and truck equivalency factors is presented in Appendices 2 - 3.

TEFs are then applied to tonnage of commodity flows moving between FAF zones to get the disaggregated data of the total number of loaded trucks. In addition to the number of loaded trucks, the concept of *empty trucks* should be considered in this procedure. In freight transportation networks, there is a concern regarding the empty backhauls which can reduce the tonnage of commodity flow per distance between the zones (Schipper et al., 1997). To have a correct estimation of the total number of long distance trucks, the percentage of empty trucks by their configuration and body type should be estimated (Table 11). Also, considering that trucks are typically working with less than full and more than fifty percent of capacity, the share of empty trucks is reduced by an additional fifty percent (Maks Inc., 2016). These factors for domestic shipments are presented in Table 11.

Table 11. Empty truck factors for domestic shipping

Body Type	Single Unit	Truck Trailer	Combination Semitrailer	Combination Double	Combination Triple
Auto	0	0	0.14	0	0
Livestock	0	0	0.2	0.16	0
Bulk	0.21	0.14	0.2	0.2	0.06
Flatbed	0.14	0.16	0.16	0.2	0.03
Tank	0.17	0.18	0.2	0.2	0
Day Van	0.12	0.07	0.1	0.04	0.07
Reefer	0.1	0.08	0.09	0.13	0
Logging	0.24	0.21	0.2	0.13	0
Other	0.1	0.06	0.25	0	0

6.3. Truck Conversion for Tennessee

6.3.1. Case Study of Commodity Flows from Nashville to Knoxville

To determine the number of trucks, as previously mentioned, the focus will be on the all types of commodity outbound flows from each FAF zone within Tennessee to all other FAF zones of the U.S. (flows between FAF zones inside Tennessee are also included). In particular, the number of trucks for all of the four FAF zones in Tennessee – for all 43 commodity types – for outbound flows from these FAF zones to all 132 other FAF zones is determined (Appendix 2 provides a list of all commodity types).

To clarify the truck conversion approach, an example of meat/seafood commodity flow tonnage conversion to number of trucks from Nashville (i.e., origin) to Knoxville (i.e., destination) for year 2012 is provided in detail (Table 12). Knowing the distance between the zones, the allocation factor is determined and applied to tonnage of meat/seafood commodity and the value for each type of truck is calculated (Table 12). The tonnage of freight assigned to five types of truck configuration is then converted into equivalent annual truck traffic values (Table 13).

Using the three-dimensional TEF factor from Appendix 3, the annual traffic values for each of the five truck types by their body styles is calculated. Next, the amount of empty trucks which are traveling between this FAF zones is determined by adjusting the results from Table 11 using the empty truck factors. The outcomes for the annual empty truck traffic and the total annual truck traffic for all types of truck configuration and body types are presented in Table 14 and Table 15.

Table 12. FAF data with zone-distance

Data Item	Value
Origin FAF zone	Nashville TN
Destination FAF zone	Knoxville TN
Commodity	Meat/seafood
Tonnage	5.0765 KTones
Value	6.9314 M$
Distance	258.1 mile

Table 13. Tonnage allocated for each truck type

Truck Type	Allocation Factors	Value KTons
Single Unit	0.142467	0.723
Truck Trailer	0.027288	0.138
Combination Semitrailer	0.751628	3.815
Combination Double	0.075218	0.381
Combination Triple	0.002031	0.010

Table 14. Annual truck traffic, loaded trucks

Body Type	Single Unit	Truck Trailer	Combination Semitrailer	Combination Double	Combination Triple
Auto	0	0	0	0	0
Livestock	0	0	0	0	0
Bulk	0.028929	0	0	0	0
Flatbed	0.643678	1.917221	2.709104	2.709104	2.709104
Tank	0	0	0	0	0
Day Van	27.73601	0	17.13222	17.13222	17.13222
Reefer	34.98282	30.1713	129.6173	129.6173	129.6173
Logging	0	0	0	0	0

Other	0.238667	0	0	0	0

Table 15. Annual truck traffic, empty trucks

Body Type	Single Unit	Truck Trailer	Combination Semitrailer	Combination Double	Combination Triple
Auto	0	0	0	0	0
Livestock	0	0	0	0	0
Bulk	0.006075	0	0	0	0
Flatbed	0.090115	0.306755	0.433457	0	0
Tank	0	0	0	0	0
Day Van	3.328322	0	1.713222	0	0
Reefer	3.498282	2.413704	11.66555	3.102484	3.102484
Logging	0	0	0	0	0
Other	0.023867	0	0	0	0

Finally, to determine the total truck traffic between Nashville and Knoxville, all types of trucks are summed up which are equal to 295 (Table 16 and Figure 10). Table 17 shows the total number of trucks (i.e., both loaded and empty trucks) with tonnage value of the meat/seafood commodity per truck.

Table 16. Annual truck traffic by truck type

Truck Type	Annual Traffic (Number of Trucks)
Single Unit	70
Truck Trailer	35
Combination Semitrailer	163
Combination Double	27
Combination Triple	0

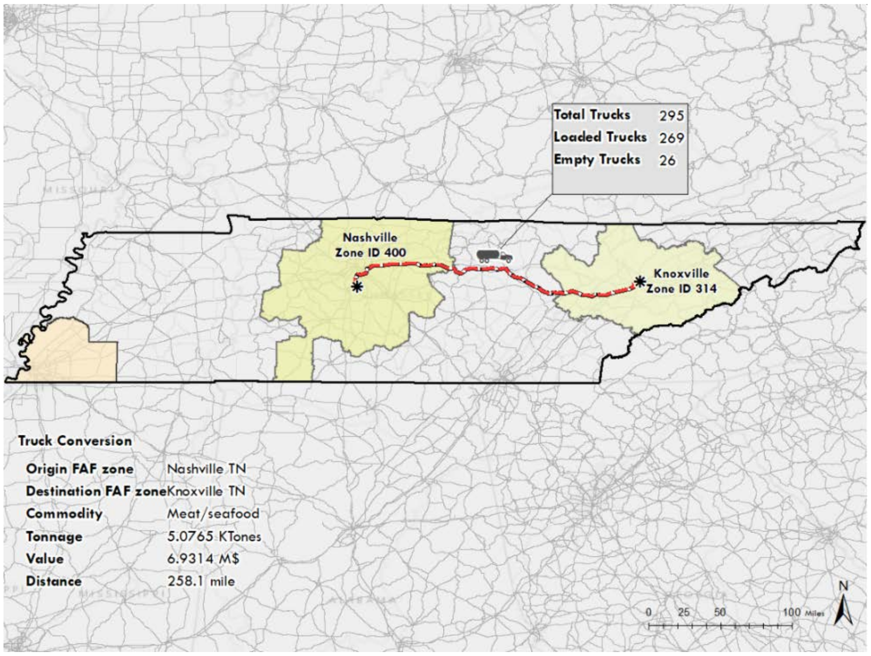


Figure 10. Schematic illustration of the meat/seafood commodity flow

This brief example describes the entire process of estimating the average number of loaded and empty trucks traveling between the FAF zones. In the next section this approach will be used to find all types of outbound commodity flows from each FAF zone within Tennessee to all other FAF zones of the U.S. (flows between FAF zones inside Tennessee are included).

Table 17. Annual truck summary

Total Freight (KTones)	**Total Trucks**	**Loaded Trucks**	**Empty Trucks**	**Tons per Truck**
5.0765	295	269	26	18.87

6.3.2. Commodity Flow Conversion to Number of Trucks for Tennessee

There are different types of freight demand projection models that have sophisticated forecasting methodologies for estimating flow volumes as well as mode shifts in transportation networks. These models use transportation demand factors (i.e., economic factors, logistics factors, transportation factors, and policy and regulatory factors) to project future changes in the transportation networks. From many available models, FAF uses macroeconomic models to project production, consumption and trade by different industry sectors (Grenzeback et al., 2013). The freight projections are demand-driven, with no constraints on the future capacity and supply changes. This means that if demand increases for a product that is transported by truck today, then the future increase in that product will also be transported by truck. Also, the increase in freight transportation demand is mainly related to economic and population growth, and different changes in the transportation system like using new technologies and changes in pricing are typically in the second order (Grenzeback et al., 2013).

To assess current and future changes in commodity flows and estimate the annual truck traffic of Tennessee, two years were selected, 2012 as the baseline year and 2045 for a future projection. Table 18 shows that almost 20 percent of freight transportation from Tennessee in 2012 moved to only five states, Mississippi (9143.884 KTons), Kentucky (8830.920 KTons), Georgia (8282.130 KTons), Alabama (6247.826 KTons) and Arkansas (5248.440 KTons). All of the domestic flows for the entire 43 types of commodities that are going out or are moving between the four FAF zones in Tennessee are determined (Figure 11). Tables 19 and 20 provide the results of this approach. In 2012, there are 10,258,691 annual truck movements which is equivalent to a 28,106 ADTT. This number is expected to significantly increase (by more than 46 percent) by year 2045 (i.e., 15,046,164 ADTT).

In addition, results show that there will be an increase in the weight carried per volume of truck capacity from 19.14 tons in 2012 to 21.95 tons in 2045 (Table 20). As such, careful attention should be given by local authorities to accommodate these significant changes.

Table 18. Domestic freight flow from Tennessee to other states for 2012, Transportation mode: Truck

From Tennessee	Total KTons	Total Ton-Mile	Total M$
Alabama	6247.826	1701.097	9580.133
Alaska	1.397	5.537	27.122
Arizona	177.728	326.783	1221.309
Arkansas	5248.440	1571.183	7859.728
California	878.749	1902.116	7530.897
Colorado	191.967	264.988	997.952
Connecticut	158.022	165.607	622.984
Delaware	29.561	24.675	219.147
Washington DC	4.582	2.659	19.875
Florida	1505.692	1202.861	5948.000
Georgia	8282.130	2585.310	15208.429
Idaho	44.594	100.381	105.829
Illinois	2867.469	1590.043	8293.297
Indiana	2271.678	977.773	6369.474
Iowa	525.131	447.110	1211.886
Kansas	756.962	614.894	2072.785
Kentucky	8830.920	2520.088	14355.975
Louisiana	807.837	447.101	2217.357
Maine	63.553	89.415	277.831
Maryland	386.515	267.850	1949.248
Massachusetts	236.829	269.721	1263.793
Michigan	964.422	645.951	3785.413
Minnesota	365.209	368.687	1540.419
Mississippi	9143.884	2277.142	10872.468
Missouri	1374.820	662.824	3386.445
Montana	13.714	27.031	71.076
Nebraska	278.276	280.636	758.640
Nevada	81.081	179.150	313.633
New Hampshire	53.255	63.506	231.423
New Jersey	453.482	393.601	2292.497
New Mexico	75.960	111.827	206.695
New York	644.236	581.352	3076.791
North Carolina	2400.514	1031.340	9036.117
North Dakota	43.652	57.577	197.496
Ohio	2548.730	1269.323	8127.371
Oklahoma	515.729	403.641	1770.766
Oregon	159.708	416.115	532.602
Pennsylvania	1941.969	1565.799	6428.630
Rhode Island	29.605	32.683	115.930
South Carolina	1390.269	615.544	3452.768
South Dakota	35.207	46.708	114.334
Tennessee	127889.186	6827.206	88931.210
Texas	3121.271	2815.899	12618.411
Utah	194.160	357.593	1046.521
Vermont	51.081	54.708	85.368
Virginia	1907.851	957.134	4981.628
Washington	117.227	308.369	690.121
West Virginia	353.465	206.349	1337.850
Wisconsin	704.823	500.670	2414.504
Wyoming	20.144	32.995	153.080

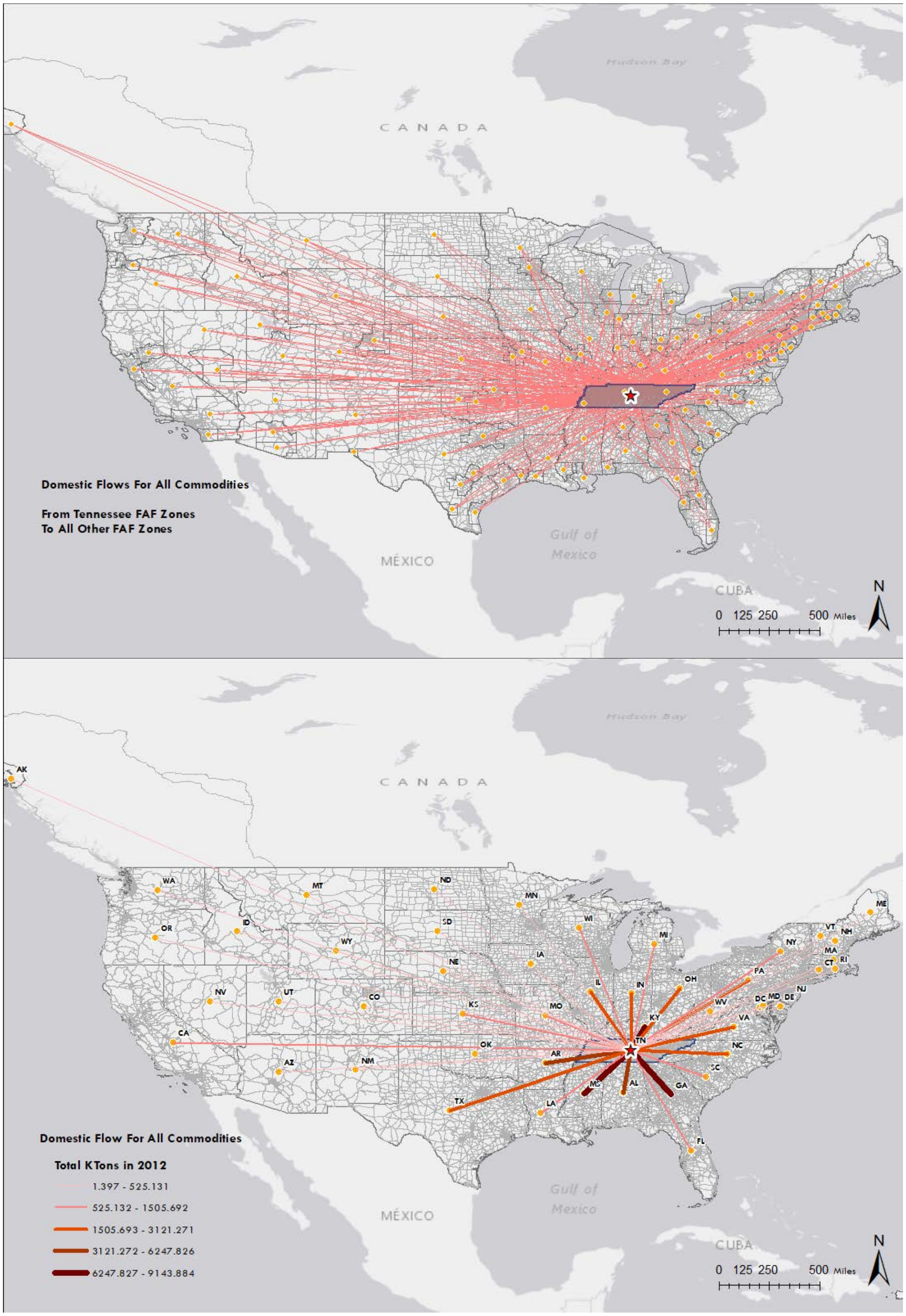


Figure 11. Commodity flow from and within Tennessee in 2012

Table 19. Annual truck traffic by truck type for 2012 and 2045

Truck Type	Annual Truck Traffic			
	2012		2045	
Single Unit	5,297,986	51.6 %	7,499,782	49.8 %
Truck Trailer	1,135,618	11 %	1,656,278	11 %
Combination Semitrailer	3,478,908	33.9 %	5,387,090	35.8 %
Combination Double	345,361	3.3 %	501,573	3.3 %
Combination Triple	818	<1 %	1,441	<1 %

Table 20. Annual truck summary for 2012 and 2045

Year	Total Freight (KTons)	Total Trucks	Loaded Trucks	Empty Trucks	Tons per Truck
2012	196,390.513	10,258,691	8,958,247	1,300,444	19.14
2045	288,724.945	15,046,164	13,151,725	1,894,439	21.95

Using the estimation of annual truck traffic for the State of Tennessee, three scenarios of CP technology implementation in freight transportation systems are developed. As previously mentioned, urban freight problems usually have local solutions. Therefore, to achieve a basic understanding of the extent of freight operation problems there should be a partnership between freight operators and local authorities. A local authority can act as the manager between different stakeholders by imposing new regulatory measures that have impact on freight operations (e.g. time-window regulations, truck weight restrictions, on street loading/unloading policies). Also, they can allocate budget for building new infrastructure and implement targeted infrastructure measures which can incentivize a modal shift towards more sustainable modes (Cherrett et al., 2012).

7. ECONOMIC IMPACTS

The freight transportation industry has four main stakeholders: receivers, shippers, freight forwarders, and planners and regulators (Rodrigue et al., 2017). These stakeholders, especially shippers, freight forwarders, and planners, are considering new policies, regulation, and logistic innovations to optimize their costs. These stakeholders often have diverse points of view with potentially conflicting values and preferences priorities. For example, a study of London freight operation showed that different low emission zone policies impact freight forwarders and will force them to either use technical approaches to comply with the new zoning policies or renew their fleet to meet the Euro-3 standard (policy-makers vs. freight operators) (Browne et al., 2005). Another example relates to truck weight restriction policies contributing to the reduction of the freight transport efficiency and leading to an increase in CO_2 emissions which could endanger citizen health (i.e., policy-makers vs. receivers) (Quak and De Koster, 2006).

Generally, the main problem is that sometimes stakeholders have personal preferences that do not allow them to have a clear and holistic vision of the long term impacts of their freight transportation system decisions. Therefore, it is necessary for each of these groups to assess the impacts of their decisions for future policies and projects in freight systems, and consider the benefits as well as the associated costs and risks that are involved.

Cost-Benefit Analysis (CBA), is an approach that quantifies the benefits and costs of new project implementation and operation during its lifetime. The ultimate goal of any CBA for urban infrastructure systems is to determine whether an initial investment in a project will result in an improvement in social welfare and make society more sustainable. In order to perform a CBA for freight transport projects, we should account for all challenges encountered in new proposed solutions. Typically, freight transportation solutions are implemented at the local level with multiple groups of stakeholders involved. Each of these stakeholders must consider all costs and benefits associated with freight transportation prior to making any major decisions to invest in technological solutions. Balm et al. (2014) categorizes these challenges into five groups listed below.

- Diversity of stakeholders and objectives
- Costs and benefits dispersed and difficult to quantify
- Ownership
- Lack of data
- Diversity of context

These challenges can be complex as solutions can affect stakeholders differently due to the uneven distribution in costs and benefits among stakeholders. Benefits can range from being quantitative (e.g., an increase in revenues for a shipper) to being qualitative (e.g., improved reliability of a transportation system). Another complexity is manifested through ownership and liability. Stakeholders are always impacted by deficiencies in freight transport systems and it is not clear who is responsible for these issues. In addition, there is no consensus on whether this problem should be approached from a public or private sector perspective. On one hand, urban diversity (i.e., geographic characteristics, population density, different policies and legislations, etc. that freight transport takes place within) challenges local and state authorities to find appropriate solutions for imminent problems. On the other hand, the private sector facing major competition is more inclined to carefully study new projects and their prospective benefits before taking the risk and investing. In addition to performing a CBA for new investments in the freight industry, it is important to address how the outcome of such analysis is applicable to different stakeholders. Such detailed assessment constitutes a challenging task due to data limitations.

Several studies have aimed to assess the impact of CP technologies in freight transportation industry (Besselink et al., 2016; O. M. Carsten and Tate, 2005; Hoffman et al., 2013; Oliveira et al., 2013), most of which focus on trucking transportation. This is in line with the fact that the trucking industry dominates the freight transportation in the United States (Worth et al., 2016), and particularly Tennessee (Maks Inc., 2016).

In this study the basic assumption is that stakeholder preferences do not play a role in the economic assessment of the costs and benefits of these technologies, the focus is rather on designing "*what-if*" scenarios. More specifically, the savings from resource waste reduction (i.e., reduction in fuel consumption and insurance premiums, Table 1) due to implementation of CP technologies will be considered as the benefits of CP systems for State of Tennessee. Furthermore, to assess the impacts of CP technology implementation in freight transportation of Tennessee for the trucking mode, a CBA with Net Present Value (NPV) approach is performed which is described in details in the next sections.

7.1. Cost-Benefit Analysis (CBA) of CP Technology: Net Present Value

Economic valuation methodologies can be utilized to measure the economic profitability of freight CP technologies. To evaluate the profitability of investments in such technologies in Tennessee, one of the main profitability indicators, the Net Present Value (NPV) approach, is used. NPV is given by Equation 7, where $\boldsymbol{i}$ is the discount rate, $\boldsymbol{N}$ is the total number of periods, $\boldsymbol{R_t}$ is the net cash inflow during the period $\boldsymbol{t}$, and $\boldsymbol{t}$ is the time of the cash flow.

$$NPV(i, N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t} \quad (7)$$

In this study, the net cash inflow at $t = 0$ will be the initial investment for the implementation of the CP technology. This amount depends on many factors, one of which is risk preference and business strategy of key stakeholders (using off-the-shelf vs. custom designed systems). There are many potential conflicts between the freight stakeholders when it comes to budget allocation for new initiatives. Key stakeholders like local governments and logistic providers prefer projects that will cover all aspects of sustainability in a city, but the main concern of freight carriers and retailers (especially small companies) lies in the economic aspects and the revenue that they can obtain from these new technologies. The main group that will benefit from these new technologies will be the customers who will have a more reliable, faster and safer freight transportation system.

After this period, the cash inflows have two main parts, the costs and the benefits related to CP technology operation. Generally, on-road transportation costs and benefits can be categorized into 22 different groups (Table 21) (Litman, 2009). Depending on the purpose of each project (i.e., scope of project and its implementation), these costs and benefits can be monetized for different transportation modes under different travel conditions (urban-peak, urban off-peak and rural). Likewise, costs and benefits associated with CP technology implementation in freight transportation are a subset of transportation costs and benefits. As discussed earlier, these items can be monetized in terms of economic, environmental, and social factors. The benefits from using CP technologies can be expressed as savings in *vehicle operation* (i.e., vehicle-based, driver-based), mainly related to savings in fuel consumption and insurance premiums (Table 21). The benefits are the positive portion of each year's cash inflows, while the negative portion of cash inflows are related to infrastructure and annual maintenance costs of CP technologies. Finally, the annual values for these costs and benefits are aggregated for each year and then discounted for the base year of the project. There are many different ways to identify the discount rate (i.e., a rate that shows the opportunity cost of money net of the rate of inflation) for the NPV approach. Due to the uncertainties that are involved in the implementation of emerging technologies like CP systems, a conservative discount rate of 10% is assumed in this study, which is higher than the real discount rate for projects from the federal Office of Management and Budget (OMB) and the Transportation Investment Generating Economic Recovery (TIGER) grant applications (LaHood, 2011).

Table 21. Transportation Cost – Benefit categories (Litman, 2009)

Item	Description	Item	Description
Vehicle Ownership	*Fixed costs of owning a vehicle*	Roadway Land Value	*The value of land used in public road rights-of-way*
Vehicle Operation	*Variable vehicle costs (e.g., fuel, oil, tires, tolls, etc.)*	Traffic Services	*Costs of providing traffic services*
Operating Subsidies	*Financial subsidies for public transit services*	Transport Diversity Value	*The value to society of a diverse transport system, particularly for non-drivers*
Travel Time	*The value of time*	Air Pollution	*Costs of vehicle air pollution emissions*
Internal Crash	*Crash costs borne directly by travelers*	GHG Emissions	*Lifecycle costs of greenhouse gases that contribute to climate change*
External Crash	*Crash costs a traveler imposes on others*	Noise	*Costs of vehicle noise pollution emissions*
Healthful Activity	*Health benefits of active transportation*	Resource Consumption	*External costs of resource consumption, particularly petroleum*
Internal Parking	*Off-street residential parking and long-term leased parking paid by users*	Barrier Effect	*Delays that roads and traffic cause to non-motorized travel*
External Parking	*Off-street parking costs not borne directly by users*	Land Use Impacts	*Increased costs of sprawled, automobile-oriented land use*
Congestion	*Congestion costs imposed on other road users*	Water Pollution	*pollution and hydrologic impacts caused by transport facilities and vehicles*
Road Facilities	*construction and operating expenses not paid by user*	Waste	*External costs associated with disposal of vehicle*

fees	*wastes*

7.1.1. Smart GPS systems

The survey from freight operators in the U.S. was discussed in the previous section as part of this larger project on CP technologies. The results point to the fact that the most common CP technology in use are various applications of smart GPS technologies. Using these technologies in a freight distribution system has a wide range of benefits from increasing in reliability to reducing GHG emissions. The focus in this analysis is on two of the future novel systems, namely Intelligent Speed Adaptation (ISA) technologies and vehicle platooning systems. With the current pace of technology, these new smart GPS systems, especially truck platooning systems, will be available in large scale in freight transportation systems in the near future. In this section, the benefits and costs of implementation are assessed and the results of modeling these systems from the literature is presented and used for the CBA.

Global Positioning System (GPS) technology for fleet management is one of the most ubiquitous technologies in freight systems. GPS fleet tracking serves three core essential features. These are constant real-time vehicle and driver location updates; vehicle status reports and maintenance planning systems. More advanced fleet management systems provide additional features such as information on fuel consumption, average vehicle speeds, number of stops, and estimated time of arrival. They can also monitor various facets of driver activity such as braking habits, bouts of reckless driving or habits that may cause vehicle stress. They can provide customized routes depending on the characteristics of the freight operators' fleet (i.e., vehicle type, size, weight, type of commodity, among others).

GPS technology uses satellites that periodically emit radio signals to GPS receivers on the ground. Triangulation is used to pinpoint a specific receiver's location. This location data needs to be transmitted to the dispatcher. This is often done using General Packet Radio Service (GPRS) (Chadil et al., 2008).GPRS can use 2G, 3G or CDMA cellular communication system's GSM network. There are many applications where smart GPS technology has been used to improve the efficiency of freight operations. These include Intelligent Speed Adaptation (ISA) systems, vehicle platooning, geotracking technologies, anti-theft tracking systems and others.

ISA uses GPS to identify the location of a vehicle (i.e., truck) and provide the speed limit and other information in that location (Figure 12). That information is used to either give feedback to the driver about his/her driving habits or take active control over the truck by limiting its speed. ISA systems are designed to alert the driver if the vehicle has entered a new variable speed zone or when different speed limits are in place due to time of day or weather conditions. Reasons for variable speed zones include schools, roadwork zones, among others (Paine et al., 2007). ISA systems can be defined within three categories, passive, voluntary, and mandatory. In a passive system, the ISA system simply alerts the driver that a speed change has occurred. In voluntary systems, the ISA system can take active control over the speed of the truck, but the driver has voluntarily turned on the system and can also disable it. Finally, in a mandatory system, the ISA system is always active and the driver cannot disengage it (O. M. Carsten and Tate, 2005).

An ISA system is a relatively autonomous system once implemented. It is composed of an in-vehicle storage device that contains a digital map with speed limits identified at every location, a vehicle navigation system which positions the vehicle on the map, and finally an engine control unit that can receive details of the current speed limit and control the vehicle's speed via engine management and active braking (Andersson and Robertsson, 2017).

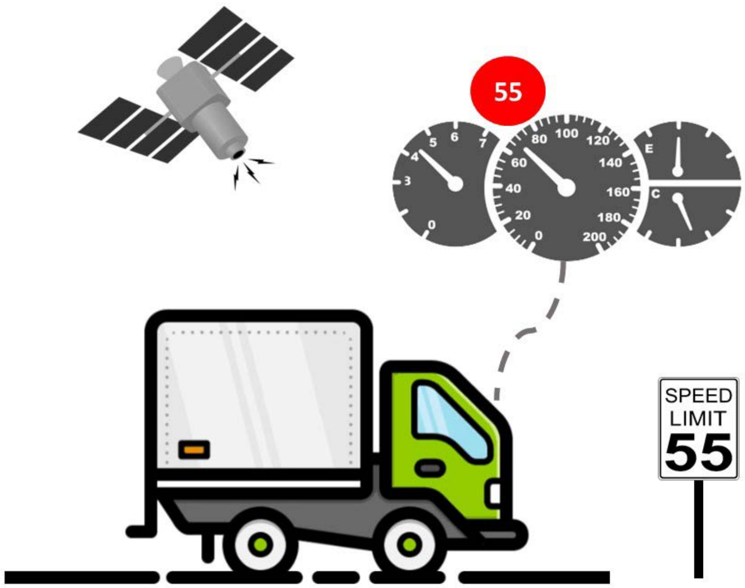


Figure 12. An illustration of the concept of ISA system

Another usage of smart GPS technologies is for managing vehicle platooning systems. Vehicle platooning is the formation of a group of vehicles (e.g., trucks) at close inter-vehicular distances (Alam et al., 2015). Using smart GPS systems coupled with information of transportation networks can manage to set the vehicles in a platoon formation (Figure 13). This will cause a significant reduction in fuel consumption due to overall drop in aerodynamic drag. This system will also focus on optimization of acceleration and braking systems to reduce emission from vehicles.

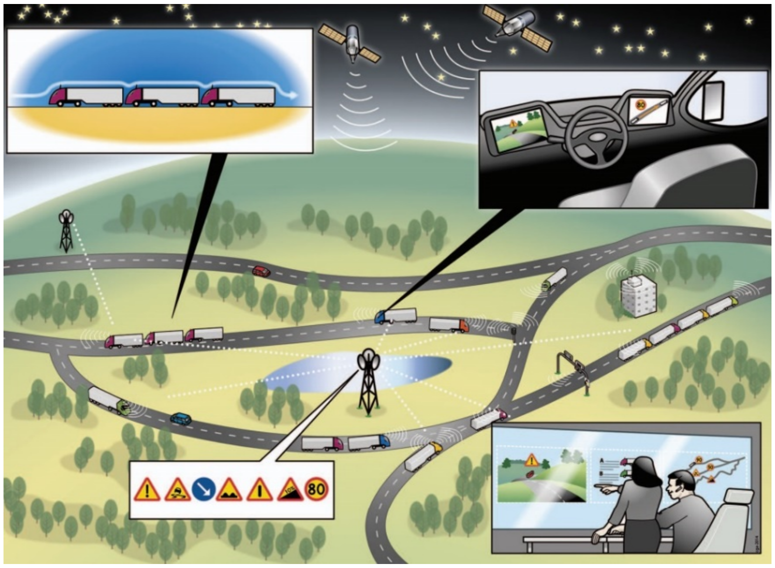


Figure 13. An illustration of future platooning system (Alam et al., 2015)

Generally the truck platooning has many environmental, economic, and safety benefits. Also the implementation of truck platooning will increase the capacity of transportation networks and decrease road congestions. The benefits of using different types of smart GPS systems is further discussed in the next section.

7.1.2. Benefits of using Smart GPS systems

There can be different forms of cost savings from using the smart GPS systems in freight transportation. Using these CP systems for monitoring freight operations can have an instant impact on route efficiency (by route correction approaches), reduction of unauthorized use of trucks (by setting limitations on working hours and geofencing methods), and management of the idle time of the fleet. Generally these systems can cause reduction in fuel consumption and labor, improve security and safety both for drivers and commodities, significant growth in productivity by improving freight visibility, and better and faster customer services. Many providers of GPS devices claim that using these devices may reduce the fuel consumption up to 20% which seems an optimistic view. NAVTEQ, the leading global provider of digital map, traffic and location data, showed that using GPS systems can reduce the travel time by 18%, comparing with an average trip without these system, and the fuel consumption by 13%. This can have the potential to reduce a vehicle fleet's CO_2 emission by up to 21%. More specifically, ISA has many potential benefits to freight providers. The most significant of which is the potential to reduce accident rates. Other benefits include reduced travel time and significant reduction in fuel consumption. In a study on ISA systems impacts on fuel consumption, Liu *et al.* use a microsimulation modelling approach to show that vehicle fuel savings will be up to 8% for urban peak and off-peak, 3% for rural road and 1% for motorway 1% in England (Liu et al., 1999).

Other benefits of ISA come in the way of increased safety and increased economic efficiency for freight providers. One method of determining safety benefits is to determine the current prevalence of speeding crashes that could be prevented by ISA (Doecke and Woolley, 2010). There are several risk factors including age of driver, location and road features/alignment than contribute to crashes due to excessive speeds. That study estimated that, in Australia, \$2.5B could be saved every year if all excessive speed was eliminated which could be expected by a properly functioning ISA system.

In addition to the benefits of ISA systems, a study on truck platooning showed that using smart adaptive cruise control systems coupled with the information of the road ahead coming from the first vehicle can reduce the fuel consumption between 3.3% - 7.7% depending on the time gap and size of the platooning trucks (Al Alam et al., 2010). This study suggests that the fuel reduction can happen instantly due to consistency in speed control and air drug reduction. Bullis (2011) suggests that with a special platoon formation of 4-m inter-truck spacing, there could be 10-15% fuel consumption reduction. Another study on truck platooning using communication technology with CP systems uses a case study in Sweden to show that overall there will be more than 5% savings in fuel consumption (Besselink et al., 2016).

In addition to all these benefits, many major insurance companies (e.g., Liberty Mutual, AAA) will reduce the insurance premiums up to 25% for the freight companies which are using new CP technologies like smart GPS systems.

7.1.3. Calculating the benefits

There are two main approaches to appraise these costs and benefits, namely actual market price and using values from different available models in the literature (Bruzelius, 2001). Both approaches are used in this study to calculate the costs of implementation and maintenance (i.e., market price) as well as savings on operational expenses (i.e., available models in the literature). As mentioned previously, there are many benefits to using smart GP systems in freight transportation. The main benefits are expressed in the reduction of vehicle operational costs. According to the yearly report by the *American Transportation Research Institute (ATRI)*, the operational costs of trucking are divided into two major groups, 1) vehicle-based costs and 2) driver-based costs (Hooper and Murray, 2017). Each of these two groups can be divided into sub-categories outlined below.

Vehicle-based

- Fuel
- Truck/Trailer Lease or Purchase Payments
- Repair and Maintenance
- Truck Insurance Premiums
- Permits and Special Licenses
- Tolls

And Driver-based

- Wages
- Benefits.

Table 22 presents the average marginal cost per mile and hour for each of these sectors for year 2012. The major part of the total cost is due to fuel cost which constituted 39 percent of the total cost in year 2012. This cost has drastic fluctuations over the years because of the U.S. economic growth and recession (Appendix 4 provides the operational costs for other years). The smart GPS systems can optimize the freight transportation fuel efficiency by controlling the travel speeds and driving behavior. The driver's related costs, wages and benefits, are the second major costs with 33 percent of total costs for 2012. According to the ATRI report in 2016, these costs have increased for the past consecutive four years and are now the largest portion of operational costs even greater than fuel cost for 2015 and 2016 (Appendix 4) (Hooper and Murray, 2017). Moreover, according to Trucking Associations (ATA) there will be a significant lack of qualified drivers in the freight industry, with an estimation that the shortage could increase to 175,000 by 2025 (Costello, 2015). This is one of the main reasons that big companies like Uber have shifted toward new technologies for self-driving trucks. In addition, truck age and type can impact some of the operational costs including insurance premiums. Insurance premium rate is often considered a fixed cost, but many insurance companies change their rates according to truck's Vehicle Miles Traveled (VMT) and CP technology equipment as a measure of risk or exposure (Hooper and Murray, 2017).

Table 22. Average marginal costs for year 2012

Motor Carrier Costs	**Costs per Mile**	**Costs per Hour**	**% Share of Total**
Vehicle-based			
Fuel Costs	$0.641	$25.63	39%
Truck/Trailer Lease or Purchase Payments	$0.174	$6.94	11%
Repair & Maintenance	$0.138	$5.52	8%
Truck Insurance Premiums	$0.063	$2.51	4%
Permits and Licenses	$0.022	$0.88	1%
Tires	$0.044	$1.76	3%
Tolls	$0.019	$0.74	1%
Driver-based			
Driver Wages	$0.417	$16.67	26%
Driver Benefits	$0.116	$4.64	7%
Total	**$1.633**	**$65.29**	**100%**

The benefits from fuel and insurance premium savings are considered in this study. To calculate the savings from operational costs of these two components, the annual average VMT for each type of trucks of this study has been used (e.g., VMT of Single Unit Truck is 12,894 and for Combination Truck is 68,262 for year 2012 (Chambers et al., 2015)). By multiplying the fuel and insurance premium costs per mile with the corresponding annual average VMT for each type of truck, and multiplying the results by the percentage of potential savings from using new systems, the associated benefits of smart GPS systems can be monetized for each year.

7.1.4. Cost of implementation of Smart GPS systems

One of the main barriers in developing large-scale CP technology adoption scenarios in freight system is the cost estimation of such technologies. Depending on the objectives and goals of any project, the cost of these systems will vary. Generally, GPS fleet tracking systems consists of two main components which are hardware and software parts. The price of these parts vary based on the options of the system from basic options (e.g., communication and navigation) to more advance features (e.g., driver safety tracking). Different companies provide different prices for GPS hardware. According to the Expert Market website, the cost of hardware of GPS fleet tracking can be categorized in three groups (Table 19) ("GPS Fleet Tracking Costs," 2018). The entry-level tier is mostly passive (not in real-time) systems that only provides basic features like trip logging and starts and stops reporting. The mid-level and advanced tiers are more suitable for larger and more complex transportation networks since they offer a web-based fleet management system. These groups of devices are laden with features like real-time tracking, geofencing, tire management, fuel usage and idle reporting, trip history logs, personnel management tools, and speed alerts, among others.

Table 23. GPS fleet tracking hardware cost

Tier	Cost (buy)	Cost (lease)	Installation Cost
Entry Level	Around $100	From $17.95/month	N/A
Mid-Level	$300-$600	From $20-$25/month	Around $100
Advanced	N/A	From $30-$65/month	Around $100+

In addition to the capital cost, there is a monthly subscription fee for the software and the updates of digital maps that ranges from $32/month per vehicle for basic systems to $60/month or more for advanced systems with more features ("What is GPS Fleet Tracking Software and How Much Does It Cost?," 2018).

Although the cost breakdown of other smart GPS systems is different from fleet tracking systems, the main concept is the same which consists of a major capital cost and monthly operational costs. For example there are several costs associated with the implementation of ISA systems. Very few studies have reported specific costs since they aren't indicative of the commercial costs. A study performed in UK estimated costs for mass production of commercial devices (O. M. J. Carsten and Tate, 2005). Major costs include information supply, direct installation and implementation of technology, and digital mapping of speed zones. Additionally, there are recurring costs of maintaining the system and updating the maps. Similar to ISA, there is no precise estimation of the commercial costs associated with the truck platooning. The major differences between different truck platooning project, which can impact the capital cost of the project significantly, are in the type of vehicle (i.e., heavy cars, passenger cars), type of control (i.e., lateral and longitudinal), infrastructure requirements (e.g., lane markings for lateral control), traffic integration system (e.g., allocation of dedicated lane for platooning), and type of sensors for vehicle to vehicle communication (Bergenhem et al., 2012).

Since there is no specific data source for the commercial costs of implementation of the ISA and truck platooning systems, the costs for GPS fleet tracking will be estimated. This also makes the assumptions more realistic due to the capability of mass implementation of this kind of system comparing to other CP technologies like ISA.

7.1.5. Scenario Assumptions

Three different scenarios for the utilization rate of GPS fleet tracking system in truck freight operations in Tennessee are considered. As mentioned earlier, the main goal of this analysis is to evaluate the benefits of CP technologies for the state of Tennessee rather than understanding the impact on different stakeholders. As such, this study provides an order-of-magnitude estimation of possible economic benefits for which the assumptions below have been made.

- The three scenarios considered to assess the impacts of GPS fleet tracking are 1) high penetration level scenario (i.e., 5% of total trucks have smart GPS systems), 2) medium penetration level scenario (i.e., 3% of total trucks have smart GPS systems) and 3) low penetration level scenario (i.e., 1% of total trucks have smart GPS systems). These three scenarios represent different levels of CP technologies penetration in Tennessee's freight system.

- There are five categories of trucks in this study (Table 8). According to the FHWA report, the average annual miles per vehicle for each type of truck for each year is determined by the report (Federal Highway Administration - US Department of Transportation, 2018). For example for year 2012, which is the base year of study, the annual average Vehicle Miles Traveled (VMT) for Single Unit Trucks is 12,894 miles and for Combination Trucks 68,262 miles. Using the corresponding annual average VMT for each type of vehicle, the operational costs for each year is determined (Table 24).

- Table 24 also provides the data for the average fuel consumption for each type of trucks according to FHWA reports (Federal Highway Administration - US Department of Transportation, 2018). Using this data, the environmental benefits from reduction in GHG emissions is calculated.

Table 24. Average annual miles and fuel consumption per vehicle, 2012-2016

Year	Single-Unit Truck		Combination Truck	
	VMT	Fuel Use (gal)	VMT	Fuel Use (gal)
2012	12,894	1,755	66,262	11,330
2013	13,116	1,785	68,155	11,653

2014	13,123	1,788	65,897	11,299
2015	12,961	1,756	61,978	10,515
2016	12,958	1,753	63,428	10,739

- The savings are estimated using two parameters. A 5% fuel consumption savings is assumed and the insurance premium for a truck with the smart GPS is reduced by 20%.

- The cost of GPS tracking systems is equal to a one-time cost of $300 for the hardware and $40 monthly for maintenance and software updates. These numbers are selected to present a mid-level or advanced GPS devices for fleet tracking. Due to inflation, the monthly costs are projected for the analysis period using annual inflation rates from U.S. Department of Labor ("Bureau of Labor Statistics Data," 2018).

- The analysis period is 5 years from 2012 to 2016. The implementation process takes place in the first year. As such, it is assumed that there are no benefits acquired in 2012.

- Since the period of the analysis is 5 years, it is assumed that the system will be outdated after this period. Therefore, there will be no residual value for the GPS devices after this period.

7.2. Results

The results of NPV for three different scenarios are presented in Tables 25, 26 and 27. In the low penetration level scenario of 1% integration of the GPS tracking system on trucks transporting commodities from (or within) the state of Tennessee, there will be approximately $78M in benefits per year emanating from savings in fuel consumption and truck insurance premiums. The NPV for this scenario is $389M for the five years of the study period. This economic benefit only comes from a total NPV of $42M on smart GPS fleet tracking systems which shows that the benefits significantly outweigh the costs. More specifically the benefits are more than 9 times the costs in term of present values. The results also indicate that the yearly savings from fuel consumption is 2.5 times more than savings from truck insurance premiums for different scenarios. For the other two scenarios, 3% and 5% of trucks with CP technologies, the economic benefits are $233M and $389M per year respectively. The results of the three scenarios show that as the number of trucks with GPS tracking system increases the economic benefits will increase linearly from $78M to $389M per year (Figure 14).

The results from the economic analysis show the possible high level of annual savings (i.e., from $78M – $389M) that the state of Tennessee authorities has been overlooked in the past years.

Table 25. CBA of smart GPS system project – First scenario 1% of total trucks

Year	2012	2013	2014	2015	2016
Benefits					

	Fuel		111,288,930.3	108,518,006.7	103,347,441.7	105,129,923.5
	Insurance Premium		44,170,490.2	43,070,712.7	41,018,519.5	41,725,985.1
Cost						
	Capital Cost	30,776,073				
	Monthly Cost		4,103,476.4	4,173,235.4	4,177,338.9	4,193,752.8
i = 10%	Present Value Factors	0.909	0.826	0.751	0.683	0.621
NPV						
	$ 389,399,608					
	$ 77,879,921/year					

Table 26. CBA of smart GPS system project – Second scenario 3% of total trucks

	Year	**2012**	**2013**	**2014**	**2015**	**2016**
Benefits						
	Fuel		333,866,791	325,554,020.2	310,042,325.1	315,389,770.5
	Insurance Premium		132,511,470.5	129,212,138.2	123,055,558.5	125,177,955.4
Cost						
	Capital Cost	92,328,219				
	Monthly Cost		12,310,429.2	12,519,706.5	12,532,017	12,581,258.6
i = 10%	Present Value Factors	0.909	0.826	0.751	0.683	0.621
NPV						
	$ 1,168,198,827					
	$ 233,639,765/year					

Table 27. CBA of smart GPS system project – Third scenario 5% of total trucks

	Year	**2012**	**2013**	**2014**	**2015**	**2016**
Benefits						
	Fuel		556,444,651.7	542,590,033.6	516,737,208.4	525,649,617.4

	Insurance Premium		220,852,450.9	215,353,563.7	205,092,597.5	208,629,925.7
Cost						
	Capital Cost	153,880,365				
	Monthly Cost		20,517,382	20,866,177.4	20,886,695	20,968,764.4
i = 10%	Present Value Factors	0.909	0.826	0.751	0.683	0.621
NPV						
	$ 1,946,998,044					
	$ 389,399,608/year					

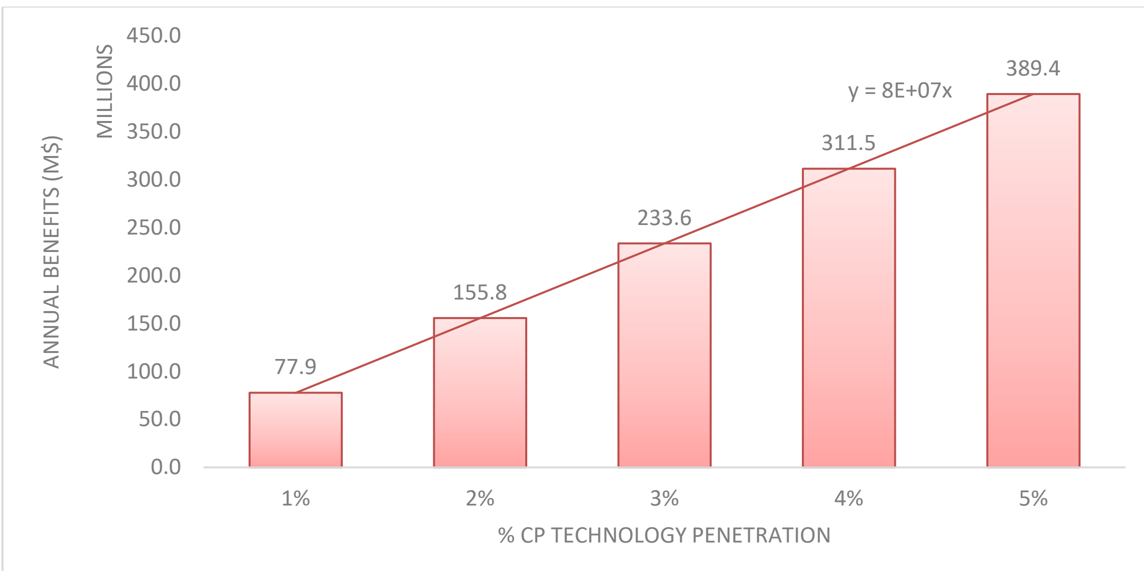


Figure 14. Economic benefits as a function of CP technology penetration

8. ENVIRONMENTAL IMPACTS

8.1. EPA's Greenhouse Gas Equivalencies Calculator

There has always been a major concern regarding the environmental impact of freight transport operations. These operations can have tremendous environmental impacts that can lead to many social issues in a city. They can impact a region in various ways including the GHG emission impacts, toxic effects both on ecosystems and human beings, land use change, noise pollution, and resource depletion (Knörr and Reuter, 2008). According to the Intergovernmental Panel on Climate Change (IPCC) the most prominent environmental impact is associated with GHG emissions (Bauer et al., 2010). As reported by the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, transportation sector accounts for more than 28 percent of total GHG emissions, which is the largest portion, in 2016 (USEPA, 2016). GHG emissions from freight transportation have the highest increasing rate among all other types of transportation sectors (Winebrake et al., 2008). With new vehicle emission standards that dictate limitation to particular pollutants like NO_X gases, CO, hydrocarbons, and particulate matter, the increasing rate of CO_2 emissions from freight transport has drawn much attention (Piecyk and McKinnon, 2010). It is also worth mentioning that 93-95 percent of the total GHG emissions from transport operations is related to CO_2 emissions (Cefic, 2011).

In order to reduce the environmental impacts of CO_2 emissions, there have been many efforts to improve the energy efficiency in freight operation industry. However, due to drastic increase in the amount of global freight trading, these attempts have not been sufficient and cities are still dealing with various environmental issues. More specifically, Tennessee is one of the states that has many critical environmental issues in land, water and especially in air quality in the past decades ("Tennessee facing critical environmental issues in coming decade" 2002). The significant rise in vehicle miles-traveled on state highways has caused major air pollution issues. According to American Lung Association, four major cities in Tennessee: Nashville, Memphis, Knoxville, and Chattanooga were in the top 25 most ozone-polluted cities in United States. This organization gave a "D" grade to the air quality of Memphis and surrounding Shelby County (the grades are from A to F). In addition, over 600,000 Tennessean are diagnosed with lung disease like asthma ("Tennessee at Risk," 2017).

Therefore to mitigate and solve these environmental issues, local governments should have both short-term and long-term solutions for the environmental impacts related to freight operations. Increasing fuel tax rate can be a short-term solution to alleviate environmental impacts of freight transport. However, there is a need for sustainable long-term solutions. Considering new technologies that are environmentally friendly is one of the main solutions that can also increase social benefits like safety and security in freight transport.

To better understand the environmental benefits from fuel savings, EPA's Greenhouse Gas Equivalencies Calculator is used in this study. From the results of the previous sections, the number of trucks in each scenario (Table 20), fuel usage for each year (Table 24), and the saving factor of using smart GPS systems is used to calculate energy savings from new CP technologies (Equation 8). This data is used as input to the EPA's GHG equivalencies calculator.

$$Energy\ Savings = No.Trucks \times Fuel\ Use \times Saving\ Factor \tag{8}$$

The input to the calculator could either be the reduction in energy or emission data which in this project is the fuel savings data. The EPA's GHG equivalencies calculator provides 18 different equivalent for energy/emission savings. The methodology for calculations of the EPA's method to convert energy/emission numbers into different types of equivalent units is described in details in EPA's website (US EPA, 2015). For instance, to convert one gallon of combusted gasoline to emitted CO_2, the heat content of the fuel per gallon is multiplied by the kg CO_2 per heat content of the fuel. This process assumes that all the carbon in the gasoline is converted to CO_2. Therefore, a conversion factor of 8,887 grams of CO_2 emissions per gallon of gasoline consumed is used (Equation 9) (National Highway Traffic Safety Administration, 2010).

$$8{,}887 \text{ gr of } CO_2/\text{gal of gasoline} = 8.887 \times 10^{-3} \text{ metric tons } CO_2/\text{gal of gasoline} \quad (9)$$

This approach can help evaluate the amount of environmental savings that CP technologies have in Tennessee by translating the abstract measurements (i.e., CO_2 equivalent from gallons of gasoline saving) into more tangible terms like the equivalent amount of carbon that can sequestered by specific area of forests or greenhouse gas emissions from cars, households, or different types of power plants. Using this method only provides an estimation of the level of environmental impacts that CP technologies can have in society.

8.2. Results

According to Table 28, fuel savings mount to 107.3, 322 and 536.6 million gallons, as a result of the implementation of smart GPS fleet tracking systems in Tennessee for each scenario, respectively. These numbers are equivalent to 190,764, 572,291 and 953,818 metric tons of CO_2 per year (Figure 15). This means that with 5% penetration of GPS systems in the trucking industry of Tennessee, CO_2 emissions will decrease by almost 1 million metric tons per year.

Moreover, the results show that with an increase in the number of trucks with smart GPS systems, there is an increasing trend in CO_2 emission reduction from the low penetration level scenario to the high penetration level scenario. The CO_2 emission reduction is 5 times higher in the high penetration scenario comparing to the low penetration scenario.

Table 28. Environmental savings from CP technologies

Savings	**1% of total trucks**	**3% of total trucks**	**5% of total trucks**
Total Fuel (million gallons)	107.3	322	536.6
Annual Fuel (million gallons/year)	21.4	64.4	107.3
CO_2 Equivalent (metric tons/year)	190,764	572,291	953,818

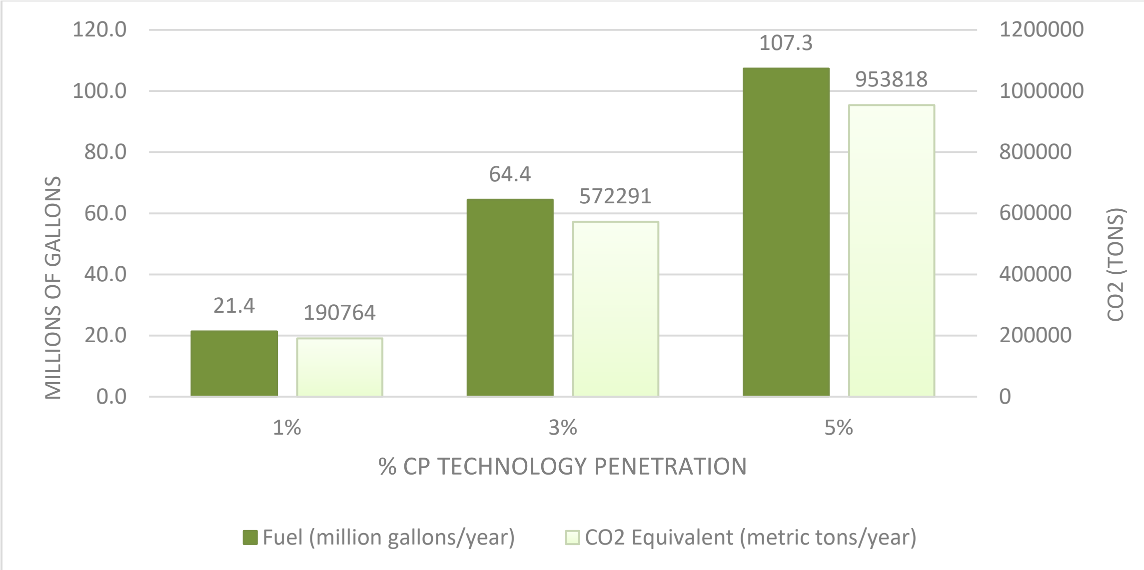


Figure 15. Environmental savings – Annual fuel, CO_2 equivalent

To help understand the impacts of the environmental benefits, a list of the equivalents of CO_2 emissions reduction is provided in Figure 16 for the first scenario. For example, the 190,764 metric tons of CO_2 per year (annual savings from 21.4 million gallons of gasoline) is equal to 1) GHG emissions savings from 40,849 passenger vehicles driven for one year, 2) GHG emissions savings from 66,468 tons of waste going to recycling instead of landfilling, 3) CO_2 emissions savings from 20,599 home's energy use for one year, 3) CO_2 emissions savings from 48.3 wind turbines running for a year, and 4) carbon sequestered by 224,692 acers of U.S. forests in one year. This indicates the level of impacts that small changes in freight transport can have on Tennessee's sustainability.

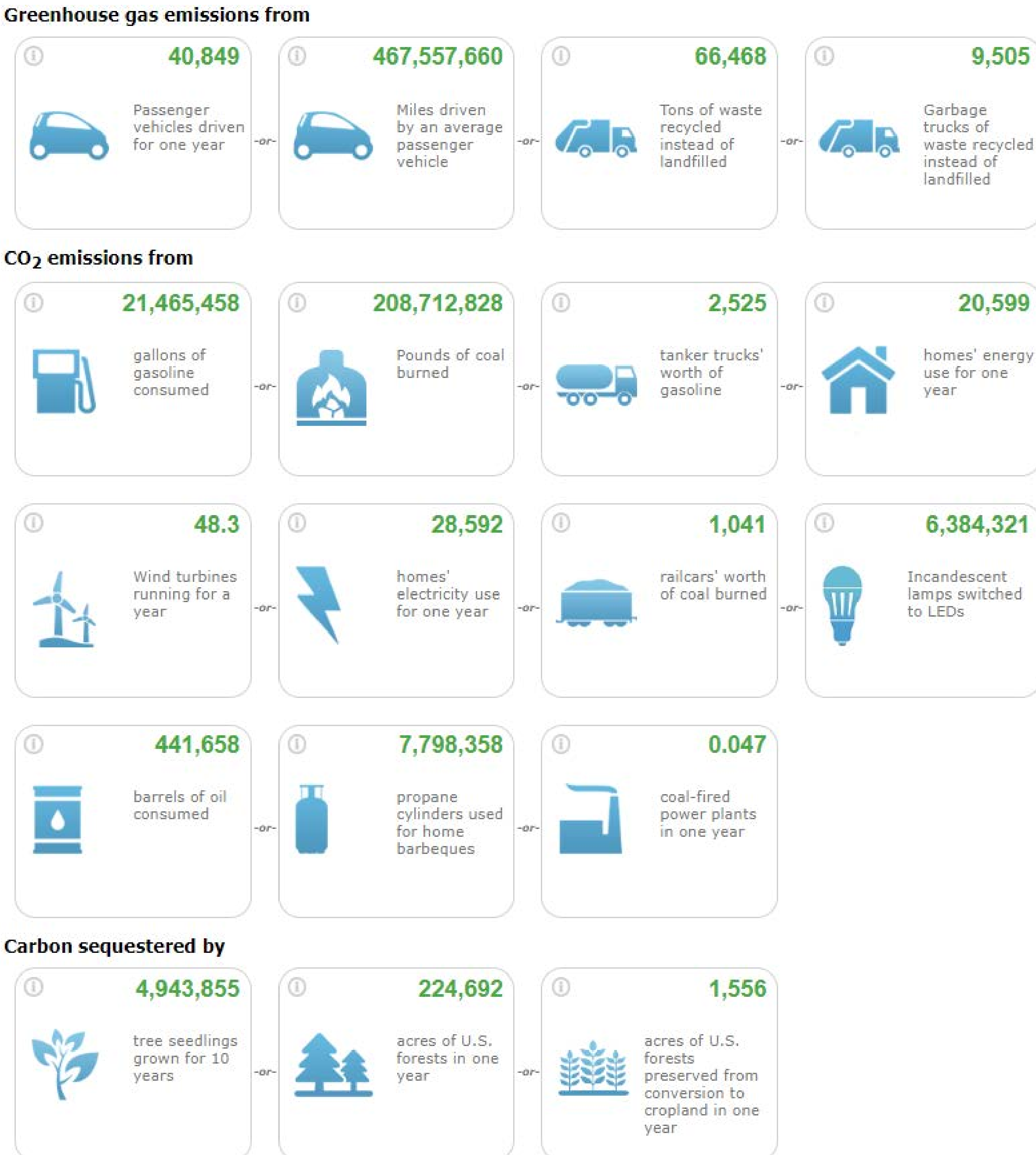


Figure 16. Equivalent terms for fuel consumption savings in the first scenario

In addition, Figure 17 presents a comparison between three smart GPS implementation scenarios for environmental savings in terms of U.S. forests preservation per year (the details of the methodology is available on EPA's website (US EPA, 2015)). Results show that the high penetration scenario and low penetration scenario can preserve 7,782 and 1,556 acres of U.S. forest from conversion into cropland per year, respectively. These numbers are almost equal to the size of Franklin State Forest and Lewis State Forest which are 7,737 and 1,287 acres, respectively ("State Forests - Tennessee Division of Forestry," 2018). This comparison shows the available significant potential of new technologies in freight transport industry.

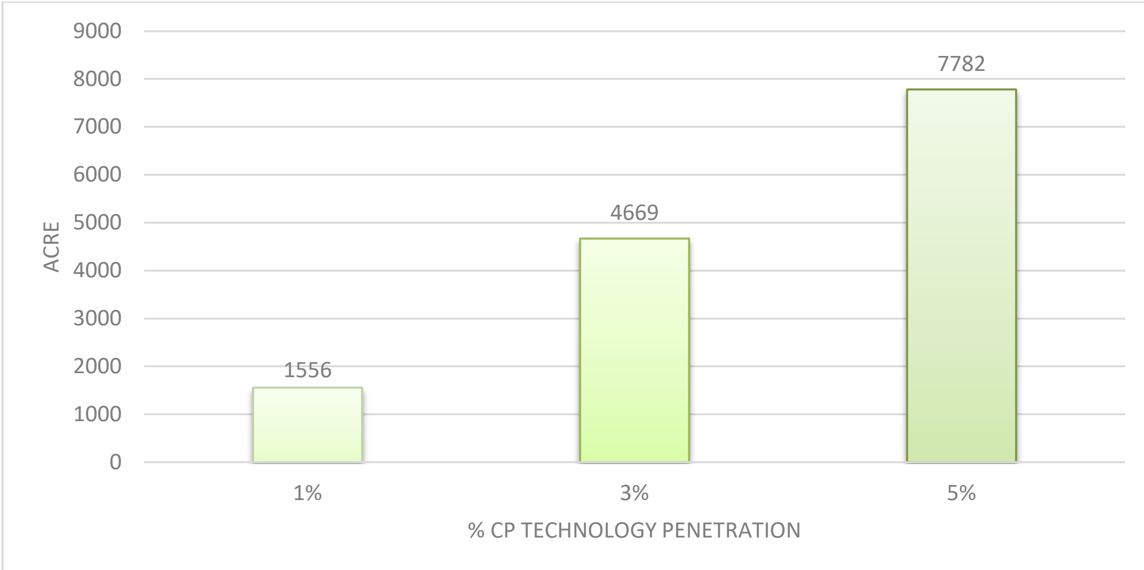


Figure 17. Environmental savings – Acres of U.S. forests preserved from conversion to cropland in one year for different scenarios

9. SOCIAL IMPACTS

9.1. Social Cost of Carbon (SC-CO_2)

As mentioned earlier, reducing the GHG emissions also have numerous social benefits. Many federal agencies, utilize the social cost of carbon (SC-CO_2) approach to measure the long-term destruction done by a ton of CO_2 emissions in U.S. dollars (EPA Fact Sheet, 2013). The result of this approach for any given year is a representative of the amount of damages avoided from any emission reductions like the benefits gained form CO_2 reduction due to implementation of CP technologies. The SC-CO_2 approach is a methodology used to estimate climate change damages especially in the case of climate impacts assessment of CO_2 emissions. This approach includes many important damages like changes in human welfare and health, variations in energy systems costs, fluctuations in net agricultural productivity, and property damages due to increased risks of flooding, and so on (EPA Fact Sheet, 2013).

In 2009, the Council of Economic Advisers and the Office of Management and Budget convened an interagency working group between different Federal agencies (i.e., Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, and Office of Science and Technology Policy, EPA, and the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury) to converge the available SC-CO_2 approaches to a harmonized consistent approach for monetizing the impacts of CO_2 emissions for regulatory impact analyses. From the recommendation of this interagency group, EPA used three integrated assessment models (IAMs) to determine an estimation of SC-CO_2:

- FUND: Climate Framework for Uncertainty, Negotiation, and Distribution model was developed by Richard Tol. This model can be used to assess climate impacts (Anthoff et al., 2009; Tol, 2009).

- DICE: Dynamic Integrated Climate and Economy model developed by William Nordhaus. This model was developed from a series of energy models (Nordhaus and Boyer, 2000).
- PAGE: Policy Analysis of the Greenhouse Effect model was developed by Chris Hope. The model helps the decision-makers to calculate the marginal impact of carbon emission (Hope, 2006).

These popular models, that combine climate processes and economic growth in one framework, are used in many peer-reviewed literature and also in the IPCC assessment. There are two key factors in SC-CO_2 models, (1) the timing of the emission release (or reduction), and (2) the discount rate (EPA Fact Sheet, 2013). The SC-CO_2 approach estimates the possible destructions that will happen after the CO_2 emission release as far as the end year of the model (e.g., year 2300). Then the models discount the estimated value of damages occurred during the run time period to present value to get the SC-CO_2. As an example, if the model runs up to year 2300, the SC-CO_2 for year 2020 represents the current value (in U.S. dollars) of climate change damages that take place between 2020 and 2300, as a result of the release of CO_2 in the year 2020. In addition, since climate change damages happen many decades later after the main environmental trigger, discount rate of the models is a key factor to find the present value of damages.

The 2009 interagency group suggested four SC-CO_2 values for each year's CO_2 emissions. The first three values are the average SC-CO_2 from three IAMs at 2.5, 3, and 5 percent discount rates (Table 29). To consider the effects of outliers for temperature change further out in the tails of the SC-CO_2 distribution, the fourth value is added to Table 29 which is SC-CO_2 estimate across all three models for the 95th percentile at a 3 percent discount rate (IAWG, 2010). This fourth value considers an extreme situation for climate change outcomes, lower-probability but higher-impact, which is useful for policymakers to estimate the level of social impacts of CO_2 emissions to society. Table 29 presents the SC-CO_2 between 2010 and 2050 in 2007 U.S. dollars. The values for the other years in between are calculated using a simple linear interpolation. Since future CO_2 emissions will cause further damages to both physical and economic systems, SC-CO_2 values should increase over time to better present the level of climatic change.

To calculate the benefits of damages avoided from CO_2 emission reductions due to the smart GPS systems, the values of SC-CO_2 for years 2013-2016 are interpolated. Since the focus of this project is on estimation of SC-CO_2, and not in uncertainties involved in regulatory impact analysis, the central value from Table 29 – average SC-CO_2 at 3 percent discount rate – is the best option to monetize the social impacts of CO2 emissions.

This approach has been used by many federal agencies, including EPA, to assess CO_2 emission impacts of different rulemakings since the interagency group recommendation release. For example this approach was used in a joint rulemaking by EPA/Department of Transportation to establish Medium- and Heavy - Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards.

Table 29. Social cost of CO_2 - in 2007 dollars for 2010 – 2050 (IAWG, 2010)

	Discount Rate

Year	5% - Avg	3% - Avg	2.5% - Avg	3% - 95th
2010	4.7	**21.4**	35.1	64.9
2015	5.7	**23.8**	38.4	72.8
2020	6.8	**26.3**	41.7	80.7
2025	8.2	**29.6**	45.9	90.4
2030	9.7	**32.8**	50	100
2035	11.2	**36**	54.2	109.7
2040	12.7	**39.2**	58.4	119.3
2045	14.2	**42.1**	61.7	127.8
2050	15.7	**44.9**	65	136.2

9.2. Results

According to Figure 18, for the low penetration scenario, which is 1% of total trucks equipped with smart GPS systems, and depending on the discount rates, the total social benefits can vary from \$5.3M to \$68.6M. These values significantly increase for the other two scenarios. For the high penetration scenario, the social benefits are between \$26.7M to \$343.1M at different discount rates. Using the average values for SC-CO_2 at 3 percent discount rate, the social benefits for low penetration scenario, medium penetration scenario and high penetration scenario are \$22.5M, \$67.4M, and \$112.3M respectively. This shows that with 3% of total trucks having smart GPS systems there could be more than \$67M social benefits. Since the freight transport is happening between all of the states and Tennessee, these social benefits will be distributed nationwide.

The figures for the social benefits of different scenarios may seem overestimated. However, prior studies estimate that the real social cost of CO_2 emission could be six times higher (\$220 per ton) than the current value for SC-CO_2 (\$37 per ton) currently used in many energy regulations and mitigation policies. Studies have shown that these models have some limitations and do not consider issues like the future impacts of climate change on the basic growth rate of the economy, which can increase the SC-CO_2 significantly (Moore and Diaz, 2015; Stanford University, 2015).

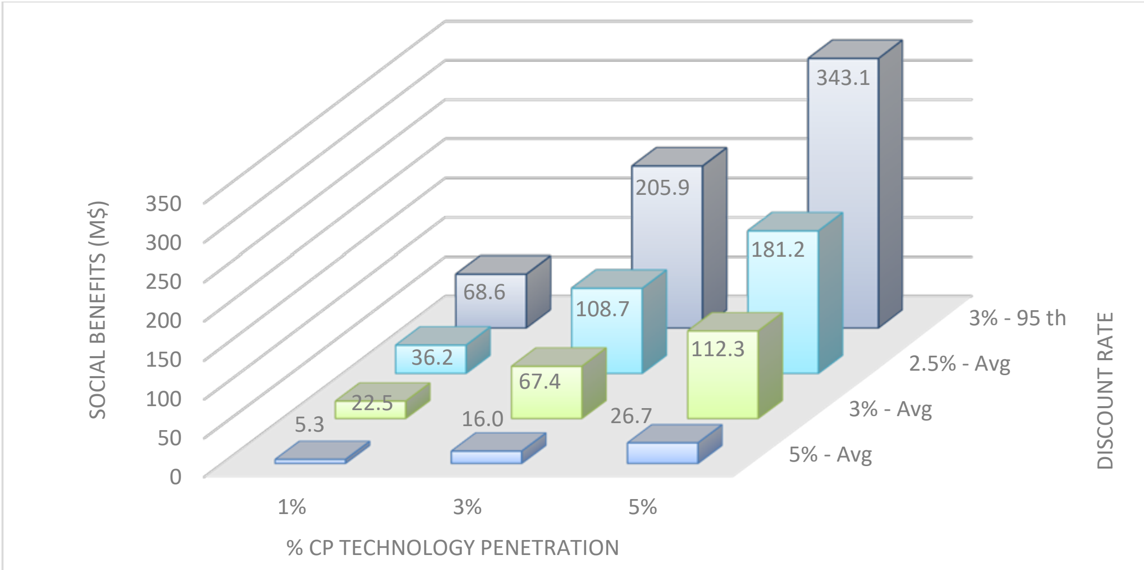


Figure 18. Social benefit as a function of CP technology penetration and discount rate

10. CONCLUSIONS AND RECOMMENDATIONS

Freight transportation systems provide a critical function in supporting the economic and social vitality in the State of Tennessee. In order to achieve efficient and effective operations, such systems are recognizing the value of using CP technologies. This research provides an overview of CP technologies that have reached the stage of industry-wide adoption. CP technologies within the freight industry, with a main focus on truck transportation, are classified into one of the five categories as defined by FHWA. This study highlights examples of implementation of CP systems in the freight industry with a focus on their impact in terms of benefits and disadvantages to the operations of the company.

Generally, CP technologies have been shown to improve efficiency of freight operations by reducing delays and providing more efficient and reliable information sharing. However, concerns have been expressed as to potential limitations to CP adoption due to issues involving information fidelity, application scalability, and acquisition/operating costs. Excessive dependency on CP systems can introduce vulnerability to accidental and intentional security breaches, a growing concern as many freight operators are shying away from investing in backup systems. As such, while many recent CP technologies have begun to take advantage of the internet as a medium for transmission, distribution and consumption of information, a number of freight companies face challenges in doing so due to reasons related to the cost of implementation as well as the increased exposure to new types of risks.

The survey and data analysis performed in this study corroborate these observations. A significant portion of survey respondents mention cost and reliability as major concerns of technology implementation. This is not ideal, as for reliability of these products to increase, wider adoption is needed. Most companies do envision themselves adopting more of these technologies in the future, with larger companies (i.e., over $1B in revenues) acting as trailblazers in such adoptions. In addition, many of freight operators believe that CP technologies have allowed them to identify and address small problems, while preventing issues of major concern that cause significant economic losses.

A sustainability assessment shows new CP technologies can result in significant benefits to the economy, the environment, and the society. A cost-benefit analysis shows that benefits can be as much as 9 times the costs in terms of present values. Social benefits can mount to more than $67M when only 3% of total trucks use smart GPS systems. And environmental benefits of 1% CP technologies penetration in the truck industry are equivalent to GHG emissions savings from 40,849 passenger vehicles driven for one year. Benefits become more significant with higher penetration rate of CP technologies, for example, at 5% usage rate of GPS systems in the trucking industry in Tennessee, CO_2 emissions will decrease by almost 1 million metric tons per year. These benefits can be achieved by promoting new CP technologies in State of Tennessee. Policy-makers can support these initiatives by setting economic incentives that can protect both the environmental and social wellness of citizens. One example would be to introduce economic incentives for freight operators buying eco-vehicles to renew their fleet or equip their old fleet with new CP technologies.

Caution should be exercised in CP-related policies. Stakeholders in the freight industry should account for all of the risks associated with new CP technologies since many of these technologies prove to be effective in pilot tests and small-scale implementations, and need to be scalable to large complex systems.

Additional considerations to expand this study include modeling the impacts of CP technologies in other modes of freight transport, such as railroad and maritime, for various CP technologies which are in practice or will be implemented in future. The major problem for modeling the impacts of CP technologies in these modes is the lack of data. Large private companies are reluctant to share proprietary data of their newest technologies.

Overall, the results of this study can be used to inform policy making for both freight operators and government officials. The study can also assist freight operators in identifying CP technologies that their current fleet is lacking, and plan for future investments accordingly. State and local governments can award special grants (e.g., U.S. Department of Transportation announced a 10-year, $4B policy to accelerate developments in vehicle automation) and incentive policies (e.g., tax breaks) for freight operators to adopt CP technologies. These will not only benefit the freight industry, but also the communities who depend on safe delivery services.

11. REFERENCES

Al Alam, A., Gattami, A., Johansson, K.H., 2010. An experimental study on the fuel reduction potential of heavy duty vehicle platooning. Presented at the Intelligent Transportation Systems (ITSC), 2010 13th International IEEE Conference on, IEEE, pp. 306–311.

Alam, A., Besselink, B., Turri, V., Martensson, J., Johansson, K.H., 2015. Heavy-duty vehicle platooning for sustainable freight transportation: A cooperative method to enhance safety and efficiency. IEEE Control Systems 35, 34–56.

Alam, M., Rajamanickam, G., 2007. Development of truck payload equivalent factor. Submitted to FHWA Office of Freight Management and Operations.

Allen, B.J., Crum, M.R., Braunschweig, C.D., 1992. The US motor carrier industry: the extent and nature of EDI use. International Journal of Physical Distribution & Logistics Management 22, 27–34.

Anderson, S., Allen, J., Browne, M., 2005. Urban logistics—how can it meet policy makers' sustainability objectives? Journal of transport geography 13, 71–81.

Andersson, D., Robertsson, S., 2017. Intelligent Transportation Systems: Capturing the socio-economic value of uncertain and flexible investments.

Anthoff, D., Tol, R.S., Yohe, G.W., 2009. Risk aversion, time preference, and the social cost of carbon. Environmental Research Letters 4, 024002.

Balm, S., Browne, M., Leonardi, J., Quak, H., 2014. Developing an evaluation framework for innovative urban and interurban freight transport solutions. Procedia-Social and Behavioral Sciences 125, 386–397.

Barnett, J., Benekohal, R., 1999. Accident reduction effects of using weigh-in-motion and automatic vehicle identification for mainline bypass around truck weigh stations. Transportation Research Record: Journal of the Transportation Research Board 233–240.

Bauer, J., Bektaş, T., Crainic, T.G., 2010. Minimizing greenhouse gas emissions in intermodal freight transport: an application to rail service design. Journal of the Operational Research Society 61, 530–542.

Behrends, S., Lindholm, M., Woxenius, J., 2008. The impact of urban freight transport: A definition of sustainability from an actor's perspective. Transportation planning and technology 31, 693–713.

Bergenhem, C., Shladover, S., Coelingh, E., Englund, C., Tsugawa, S., 2012. Overview of platooning systems. Presented at the Proceedings of the 19th ITS World Congress, Oct 22-26, Vienna, Austria (2012).

Besselink, B., Turri, V., van de Hoef, S.H., Liang, K.-Y., Alam, A., Mårtensson, J., Johansson, K.H., 2016. Cyber–physical control of road freight transport. Proceedings of the IEEE 104, 1128–1141.

Board, T.R., National Academies of Sciences and Medicine, E., 2010. Freight-Demand Modeling to Support Public-Sector Decision Making. The National Academies Press, Washington, DC. https://doi.org/10.17226/14445

Booth, D., Haas, H., McCabe, F., Newcomer, E., Champion, M., Ferris, C., Orchard, D., 2004. Web services architecture, February 2004. W3C Working Group Note.

Brown, V., Anderson, M., Balducci, P., Orban, J., Kiefer, M., Desautels, A., 2009. Evaluation of the National CVISN Deployment Program: Volume 1 Final Report.

Browne, M., Allen, J., Anderson, S., 2005. Low emission zones: the likely effects on the freight transport sector. International Journal of Logistics: Research and Applications 8, 269–281.

Bullis, K., 2011. How vehicle automation will cut fuel consumption. MIT's Technology Review. October 24.

Bureau of Labor Statistics Data [WWW Document], 2018. URL https://data.bls.gov/pdq/SurveyOutputServlet (accessed 6.28.18).

Carr, N., McCullagh, P., 2014. Geofencing on a mobile platform with alert escalation. Presented at the International Workshop on Ambient Assisted Living, Springer, pp. 261–265.

Carsten, O.M., Tate, F., 2005. Intelligent speed adaptation: accident savings and cost–benefit analysis. Accident Analysis & Prevention 37, 407–416.

Carsten, O.M.J., Tate, F.N., 2005. Intelligent speed adaptation: accident savings and cost–benefit analysis. Accident Analysis & Prevention 37, 407–416. https://doi.org/10.1016/j.aap.2004.02.007

Cefic, E., 2011. Guidelines for Measuring and Managing CO2 Emission from Freight Transport Operations. Cefic Report 1, 1–18.

Chadil, N., Russameesawang, A., Keeratiwintakorn, P., 2008. Real-time tracking management system using GPS, GPRS and Google earth. Presented at the Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, 2008. ECTI-Con 2008. 5th International Conference on, IEEE, pp. 393–396.

Chambers, M., Goworowska, J., Rick, C., Sedor, J., 2015. Freight facts and figures, 2015.

Cherrett, T., Allen, J., McLeod, F., Maynard, S., Hickford, A., Browne, M., 2012. Understanding urban freight activity–key issues for freight planning. Journal of Transport Geography 24, 22–32.

Costello, B., 2015. ATA's Trucking Economic Review 17.

Crainic, T.G., Gendreau, M., Potvin, J.-Y., 2009. Intelligent freight-transportation systems: Assessment and the contribution of operations research. Transportation Research Part C: Emerging Technologies 17, 541–557.

Damodaran, A., 2018. Margins by sector (us). NYU. Available online at http://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/margin.html.

Davis, L.C., 2004. Effect of adaptive cruise control systems on traffic flow. Physical Review E 69, 066110. https://doi.org/10.1103/PhysRevE.69.066110

Davis, S.C., 2002. Transportation Energy Data Book. Edition 22. DIANE Publishing.

Demery, P., 2017. Trucking services firm J.B. Hunt rolls out a freight marketplace [WWW Document]. Digital Commerce 360. URL https://www.digitalcommerce360.com/2017/04/21/trucking-services-firm-j-b-hunt-rolls-freight-marketplace/ (accessed 7.27.17).

Doecke, S., Woolley, J., 2010. Cost benefit analysis of intelligent speed assist. Adelaide: Centre for Automotive Safety Research.

Edwards, M.C., Donelson, J., Zavis, W.M., Prabhakaran, A., Brabb, D.C., Jackson, A.S., 2005. Improving Freight Rail Safety with On-Board Monitoring and Control Systems, in: Joint Rail. ASME, pp. 117–122. https://doi.org/10.1115/RTD2005-70047

EPA Fact Sheet, 2013. Social Cost of Carbon. United States Environmental Protection Agency (EPA): Washington, DC, USA.

Ervin, R., Sayer, J., LeBlanc, D., Bogard, S., Mefford, M., Hagan, M., Bareket, Z., Winkler, C., 2005. Automotive Collision Avoidance System Field Operational Test Report: Methodology and Results.
Evaluation of the National CVISN Deployment Program, 2005. . Intelligent Transportation Systems.
Ewing, T., 2017. Reduce Insurance Costs by using Insurance GPS Tracking.
Federal Highway Administration - US Department of Transportation, P. and G.A.O. of H.P.I., 2018. Highway Statistics Series.
Freight Information Real-Time System for Transport (FIRST), 2003. . U.S. Department of Transportation.
Fukui, M., Nishinari, K., Yokoya, Y., Ishibashi, Y., 2009. Effect of real-time information upon traffic flows on crossing roads. Physica A: Statistical Mechanics and its Applications 388, 1207–1212. https://doi.org/10.1016/j.physa.2008.12.037
GPS Fleet Tracking Costs [WWW Document], 2018. URL https://www.expertmarket.com/fleet-management/costs
Grenzeback, L.R., Brown, A., Fischer, M.J., Hutson, N., Lamm, C.R., Pei, Y.L., Vimmerstedt, L., Vyas, A.D., Winebrake, J.J., 2013. Transportation Energy Futures Series: Freight Transportation Demand: Energy-Efficient Scenarios for a Low-Carbon Future. National Renewable Energy Lab.(NREL), Golden, CO (United States).
Grove, K, Atwood, J., Hill, P., Fitch, G., Blanco, M., Guo, F., Richards, T., 2016. Field Study of Heavy-Vehicle Crash Avoidance Systems - Final Report.
Grove, Kevin, Atwood, J., Hill, P., Fitch, G., Blanco, M., Guo, F., Russell, S., Marchese, M., Bartholomew, P., Richards, T., 2016. Field Study of Heavy-Vehicle Crash Avoidance Systems.
Hans, G., 2016. U.S. lawmakers say with new technology, it’s time to inspect all inbound containers - Westar International Forwarders. [WWW Document]. Westar International Forwarders. URL http://www.westarusa.com/u-s-lawmakers-say-new-technology-time-inspect-inbound-containers/ (accessed 5.1.18).
Hernandez, S. V., Tok, A., Ritchie, S.G., 2016. Integration of Weigh-in-Motion (WIM) and inductive signature data for truck body classification. Transportation Research Part C: Emerging Technologies 68, 1–21. https://doi.org/10.1016/J.TRC.2016.03.003
Hisano, A., Nakamura, A., 2002. State surveillance system and method for an object and the adjacent space, and a surveillance system for freight containers. US 6879257 B2.
Hoffman, A.J., Lusanga, K., Bhero, E., 2013. A combined GPS/RFID system for improved cross-border management of freight consignments. Presented at the AFRICON, 2013, IEEE, pp. 1–8.
Hooper, A., Murray, D., 2017. An Analysis of the Operational Costs of Trucking: 2017 Update.
Hope, C., 2006. The marginal impact of CO2 from PAGE2002: an integrated assessment model incorporating the IPCC’s five reasons for concern. Integrated assessment 6.
Hribernik, K.A., Warden, Tobias, Thoben, K.-D., Herzog, Otthein, 2010. AN INTERNET OF THINGS FOR TRANSPORT LOGISTICS - AN APPROACH TO CONNECTING THE INFORMATION AND MATERIAL FLOWS IN AUTONOMOUS COOPERATING LOGISTICS PROCESSES. MITIP.
Huynh, N., Smith, D., Harder, F., 2016. Truck appointment systems: where we are and where to go from here. Transportation Research Record: Journal of the Transportation Research Board 1–9.

IAWG, U., 2010. Technical support document: Social cost of carbon for regulatory impact analysis under executive order 12866. Interagency Working Group on Social Cost of Carbon, United States Government, Washington, DC.
Jacob, B., Feypell-de La Beaumelle, V., 2010. Improving truck safety: Potential of weigh-in-motion technology. IATSS research 34, 9–15.
Jedermann, R., Behrens, C., Westphal, D., Lang, W., 2006. Applying autonomous sensor systems in logistics—Combining sensor networks, RFIDs and software agents. Sensors and Actuators A: Physical 132, 370–375.
Jutilla, D., 2012. uShip Survey: 7 in 10 Truckers Using Mobile More Often for Business; Smartphones, GPS Units on Collision Course? [WWW Document]. URL https://about.uship.com/press-release/uship-survey-7-in-10-truckers-using-mobile-more-often-for-business-smartphones-gps-units-on-collision-course/
Knörr, W., Reuter, C., 2008. EcoTransIT: Ecological Transport Information Tool Environmental, Methodology and Data. Update.
LaHood, R., 2011. Notice of Funding Availability for the Department of Transportation’s National Infrastructure Investments Under the Full-Year Continuing Appropriations. US Department of Transportation. Federal Register 76, 50310.
Litman, T., 2009. Transportation cost and benefit analysis. Victoria Transport Policy Institute 31.
Liu, R., Tate, J., Boddy, R., 1999. Simulation modelling on the network effects of EVSC. Deliverable 11.3 of External Vehicle Speed Control Project. Institute for Transport Studies, University of Leeds, UK.
Maks Inc., 2016. FAF4 Freight Traffic Assignment.
Marell, A., Westin, K., 1999. Intelligent transportation system and traffic safety – drivers perception and acceptance of electronic speed checkers. Transportation Research Part C: Emerging Technologies 7, 131–147. https://doi.org/10.1016/S0968-090X(99)00016-9
Mika, S., 2010. Telematics Sensor-Equipped Trucks Help UPS Control Costs.
Mirzabeiki, V., 2013. An overview of freight intelligent transportation systems. International Journal of Logistics Systems and Management 14, 473. https://doi.org/10.1504/IJLSM.2013.052748
Moir, W.M., Vandy, S.C., 2017. Systems and methods for freight tracking and monitoring.
Möller, D.P., 2016. Guide to computing fundamentals in cyber-physical systems. Computer Communications and Networks. Springer, Heidelberg.
Moore, F.C., Diaz, D.B., 2015. Temperature impacts on economic growth warrant stringent mitigation policy. Nature Climate Change 5, 127.
National Highway Traffic Safety Administration, 2010. Light-duty vehicle greenhouse gas emission standards and corporate average fuel economy standards; final rule. Federal Register 40, 25323–25728.
National Research Council, 1990. Truck weight limits: issues and options. Transportation Research Board, National Research Council.
National Research Council (US). Committee on Freight Transportation Information Systems Security, 2003. Cybersecurity of Freight Information Systems: A Scoping Study. Transportation Research Board Computer Science and Telecommu.
Nordhaus, W.D., Boyer, J., 2000. Warming the world: economic models of global warming. MIT press.

Oliveira, R.R., Noguez, F.C., Costa, C.A., Barbosa, J.L., Prado, M.P., 2013. SWTRACK: An intelligent model for cargo tracking based on off-the-shelf mobile devices. Expert Systems with Applications 40, 2023–2031.

Paine, M., Paine, D., Griffiths, M., Germanos, G., 2007. In-vehicle intelligent speed advisory systems. Presented at the Proceedings of the 20th International Conference on the Enhanced Safety of Vehicles.

Piecyk, M.I., McKinnon, A.C., 2010. Forecasting the carbon footprint of road freight transport in 2020. International Journal of Production Economics, Integrating the Global Supply Chain 128, 31–42. https://doi.org/10.1016/j.ijpe.2009.08.027

Poon, T.C., Choy, K.L., Chow, H.K.H., Lau, H.C.W., Chan, F.T.S., Ho, K.C., 2009. A RFID case-based logistics resource management system for managing order-picking operations in warehouses. Expert Systems with Applications 36, 8277–8301. https://doi.org/10.1016/j.eswa.2008.10.011

Quak, H.J., De Koster, M., 2006. Urban distribution: The impacts of different governmental time-window schemes.

Reclus, F., Drouard, K., 2009a. Geofencing for fleet & freight management, in: 2009 9th International Conference on Intelligent Transport Systems Telecommunications, (ITST). IEEE, pp. 353–356. https://doi.org/10.1109/ITST.2009.5399328

Reclus, F., Drouard, K., 2009b. Geofencing for fleet & freight management. Presented at the Intelligent Transport Systems Telecommunications,(ITST), 2009 9th International Conference on, IEEE, pp. 353–356.

Rodrigue, J.-P., Comtois, C., Slack, B., 2017. The geography of transport systems, 4th edition. ed. Routledge, Taylor & Francis Group, London ; New York.

Salmasi, A., 1989. An overview of the OmniTRACS-The first operational two-way mobile Ku-band satellite communications system. Presented at the Institute of Navigation Satellite Division, 2nd International Technical Meeting, pp. 127–131.

Schipper, L., Scholl, L., Price, L., 1997. Energy use and carbon emissions from freight in 10 industrialized countries: an analysis of trends from 1973 to 1992. Transportation Research Part D: Transport and Environment 2, 57–76.

Seiler, P., Song, B., Hedrick, J.K., 1998. Development of a Collision Avoidance System. https://doi.org/10.4271/980853

Srour, J., Kennedy, J., Jensen, M., Mitchell, C., 2003. Freight Information Real-Time System for Transport Evaluation Final Report. Washington, DC.

Stanford University, 2015. Estimated social cost of climate change not accurate, Stanford scientists say [WWW Document]. Stanford News. URL https://news.stanford.edu/2015/01/12/emissions-social-costs-011215/ (accessed 7.12.18).

State Forests - Tennessee Division of Forestry [WWW Document], 2018. URL https://www.tn.gov/agriculture/forests/state-forests.html (accessed 7.11.18).

Systematics, C., 2005. An initial assessment of freight bottlenecks on highways.

Tate, W.H., Abkowitz, M.D., 2012. Emerging technologies applicable to hazardous materials transportation safety and security. Journal of Transportation Safety & Security 4, 244–257.

Tennessee at Risk: New Report “State of Risk” Reveals Broad, Adverse Impact on Tennessee Communities and Public Health from Threatened EPA Cuts [WWW Document], 2017. . Environmental Defense Fund. URL https://www.edf.org/media/tennessee-risk-new-

report-state-risk-reveals-broad-adverse-impact-tennessee-communities-and (accessed 7.1.18).
Tennessee facing critical environmental issues in coming decade [WWW Document], 2002. . Vanderbilt University. URL https://news.vanderbilt.edu/2002/09/23/tennessee-facing-critical-environmental-issues-in-coming-decade-say-vanderbilt-researchers-60194/ (accessed 7.2.18).
Tiedemann, E.G., Jacobs, I.M., Salmasi, A.B., Bernard, T.J., 1990. The OmniTRACS/sup R/Mobile Satellite Communications and Positioning System. Presented at the Transportation Electronics, 1990. Vehicle Electronics in the 90's: Proceedings of the International Congress on, IEEE, pp. 503–507.
Tol, R.S., 2009. An analysis of mitigation as a response to climate change. Copenhagen Consensus on.
Top 50 Trucking Companies [WWW Document], 2012. . SJ Consulting Group. URL http://www.joc.com/trucking-logistics/top-50-trucking-companies-2012 (accessed 7.27.17).
Torrey, I., Ford, W., 2017. Cost of Congestion to the Trucking Industry: 2017 Update.
Tuttle, J.R., 1997. Traditional and emerging technologies and applications in the radio frequency identification (RFID) industry. Presented at the Radio Frequency Integrated Circuits (RFIC) Symposium, 1997., IEEE, IEEE, pp. 5–8.
US EPA, O., 2015. Greenhouse Gases Equivalencies Calculator - Calculations and References [WWW Document]. US EPA. URL https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references (accessed 7.2.18).
USEPA, E., 2016. Inventory of US greenhouse gas emissions and sinks: 1990–2016. Washington, DC, USA, EPA.
Wandel, S., 2006. Method and a device for detecting intrusion into or tampering with contents of an enclosure. US 7659816 B2.
What is GPS Fleet Tracking Software and How Much Does It Cost? [WWW Document], 2018. URL https://priceithere.com/gps-fleet-tracking-prices/
Winebrake, J.J., Corbett, J.J., Falzarano, A., Hawker, J.S., Korfmacher, K., Ketha, S., Zilora, S., 2008. Assessing Energy, Environmental, and Economic Tradeoffs in Intermodal Freight Transportation. Journal of the Air & Waste Management Association 58, 1004–1013. https://doi.org/10.3155/1047-3289.58.8.1004
Wolfe, M., Troup, K., 2005a. The freight technology story: Intelligent freight technologies and their benefits.
Wolfe, M., Troup, K., 2005b. The Freight Technology Story: Intelligent Freight Technologies and Their Benefits. Washington, DC.
Worth, M., Guerrero, S., Meyers, A., 2016. 2016 Freight Quick Facts Report.
Zhang, J., Wang, F.-Y., Wang, K., Lin, W.-H., Xu, X., Chen, C., 2011. Data-driven intelligent transportation systems: A survey. IEEE Transactions on Intelligent Transportation Systems 12, 1624–1639.
Zhang, X., Zeng, Q., Chen, W., 2013. Optimization Model for Truck Appointment in Container Terminals. Procedia - Social and Behavioral Sciences 96, 1938–1947. http://dx.doi.org/10.1016/j.sbspro.2013.08.219

Appendix 1: Online Survey from Freight Operators

Survey for Freight Companies on Use of Cyber Physical (CP) Technologies

CP systems are defined as co-engineered interacting networks of physical and computational components. Please refer to the first page of this survey for more detailed definitions and categorization of CP technologies.

1. What is the size of your company in annual revenues?
    a. Under $500,000
    b. $500,000 - $1 million
    c. $1 - $10 million
    d. $10 - $100 million
    e. $100 million to $1 billion
    f. More than $1 billion

2. What are the primary locations/terminals of your company?
    a. List here

3. Are you currently employing any CP technologies in freight operations?
    a. Yes
    b. No, proceed to question 13

4. Are you using CP systems for asset tracking of trailers, containers, chassis and pallets?
    a. Yes
        i. Mobile Communications
        ii. RFID (Radio-Frequency Identification)
        iii. GPS devices (battery or other)
        iv. Tools to monitor location/status of assets
            1. List Technologies
        v. Any level of Autonomous Trucking(e.g. merging assistants, driver aids)
        vi. Other, please describe
    b. No

5. Are you using CP systems for asset tracking of power units?
    a. Yes
        i. Mobile Communications
        ii. RFID (Radio-Frequency Identification)
        iii. GPS devices (battery or other)
        iv. Tools to monitor location/status of assets
            1. List Technologies
        v. Any level of Autonomous Trucking(e.g. merging assistants, driver aids)
        vi. Other, please describe
    b. No

6. Are you using CP systems to assist in on-board status monitoring of cargo. This includes sensors to monitor vehicle operating parameters, the condition of cargo and safety mechanisms to monitor load tampering.
    a. Yes

        i. Vehicle Operating Parameters (e.g. engine RPM, oil temperature, speed)
        ii. Cargo and Freight Condition (e.g. temperature sensors, ethylene detectors)
        iii. Intrusion and Tamper Detection
        iv. Remote Locking and Unlocking
        v. Others, please describe
    b. No

7. Are you using CP technologies to improve the efficiency of gateway facilitation? Gateways can include terminal gates, highway inspection stations and border crossings.
    a. Yes
        i. Smart Cards
        ii. RFID
        iii. Weigh-In-Motion
        iv. Route adherence monitoring/Geo-Fencing
        v. Nonintrusive inspection technologies
            1. List Technologies
        vi. Others, please describe
    b. No

8. Are you using CP technologies to allow for freight status information transmission? This includes exchange of information related to freight flows generally using the web.
    a. Yes (e.g. web portals, electronic receipts/invoicing)
        i. List Technologies
    b. No

9. Are you using CP technologies to allow for network status information to be tracked? These include services that integrate data from cameras and road sensors, geo-fencing automatic updates and systems that monitor traffic congestion, weather conditions, and incidents.
    a. Yes
        i. Congestion alerts and avoidance
        ii. Online carrier scheduling support
    b. No

10. Do you believe that benefits gained from investments you have made in CP technologies outweigh the costs of implementing and maintaining them?
    a. Yes
        i. Why?
    b. No
        i. Why not?

11. Have you noticed an increase in annual revenue after using CP technologies?
    a. No
    b. Yes
        i. How significant is the increase?
            1. Less than 10%

2. 10%-20%
3. 20%-50%
4. More than 50%

12. What are the challenges you face in implementing CP technologies for your operations?
    a. Cost of implementation
    b. Policy
    c. Risk
    d. Reliability
    e. Payback return on investment
    f. Other, please describe

13. What are your concerns regarding freight CP technologies?
    a. Data breach
    b. Cost versus reward
    c. Increased vulnerability
    d. Privacy issues
    e. Technology outdated too fast
    f. Other, please describe

14. Do you intend to make further investments in CP technologies, and if so, what technologies/systems?
    a. Yes
        i. Why?
    b. No
        i. Why not?

15. What are some possible reasons for lack of investment in CP technologies?
    a. Costs
    b. Payback return
    c. Security Risks
    d. Customer base does not require them
    e. Other, please describe

16. Do you envision future investments in CP technologies?
    a. Yes
        i. In which category
            1. Asset Tracking
            2. On-board status monitoring
            3. Gateway Facilitation
            4. Freight Status Information
            5. Network Status Information
    b. No

Appendix 2: FAF Commodity Categories

FAF Commodity Groups

Index	Description
1	Live animals and live fish
2	Cereal grains
3	Other agricultural products
4	Animal feed
5	Meat/seafood
6	Milled grain products
7	Other foodstuffs
8	Alcoholic beverages
9	Tobacco products
10	Building stone
11	Natural sands
12	Gravel and crushed stone
13	Nonmetallic minerals
14	Metallic ores and concentrates
15	Coal
16	Crude Petroleum
17	Gasoline and aviation turbine fuel
18	Fuel oils
19	Coal and petroleum products
20	Basic chemicals
21	Pharmaceutical products
22	Fertilizers
23	Chemical products and preparations
24	Plastics and rubber
25	Logs and other wood in the rough
26	Wood products
27	Pulp, newsprint, paper, and paperboard
28	Paper or paperboard articles
29	Printed products
30	Textiles and leather
31	Nonmetallic mineral products
32	Base metal in primary or finished forms
33	Articles of base metal
34	Machinery
35	Electronic and electrical equipment
36	Motorized and other vehicles
37	Transportation equipment
38	Precision instruments and apparatus
39	Furniture
40	Miscellaneous manufactured products
41	Waste and scrap
42	Commodity unknown
43	Mixed freight

Appendix 3: Truck Equivalency Factors

Truck Equivalency Factors – Single Unit (SU)

Commodity	Auto	Livestock	Bulk	Flatbed	Tank	Day Van	Reefer	Logging	Other
1	0	0	0.0066	0.04922	0.00111	0.00419	0.00173	0	0
2	0	0	0.02675	0.0086	0.00103	0.00032	0.00003	0	0.00003
3	0	0	0.01069	0.01981	0.00102	0.00996	0.00942	0	0.00147
4	0	0	0.01463	0.02657	0.00562	0.00334	0.00137	0	0.00034
5	0	0	0.00004	0.00089	0	0.03835	0.04837	0	0.00033
6	0	0	0	0.00025	0	0.15767	0.00216	0	0.00011
7	0	0	0.00001	0.00032	0.00073	0.02096	0.02048	0	0.02192
8	0	0	0	0.00002	0	0.02133	0.00286	0	0.02956
9	0	0	0	0	0	0.06785	0.04242	0	0.01498
10	0	0	0.01399	0.01865	0.00029	0.00115	0	0	0.00185
11	0	0	0.02362	0.00638	0	0.00107	0	0	0.00058
12	0	0	0.02337	0.00292	0	0	0	0.00002	0.00034
13	0	0	0.02393	0.00255	0.00119	0.0008	0.00002	0	0.00048
14	0	0	0.01773	0.01261	0	0	0	0	0
15	0	0	0.01973	0.00307	0	0	0	0	0.001
16	0	0	0.00685	0.02455	0.01041	0.00086	0	0	0.01333
17	0	0	0	0.00186	0.02298	0.02755	0	0	0.00225
18	0	0	0.00026	0.00328	0.03386	0.00038	0	0	0.00261
19	0	0	0.00116	0.01074	0.0466	0.00273	0	0	0.00122
20	0	0	0.00171	0.02421	0.0146	0.01697	0	0	0.00266
21	0	0	0	0	0	0.10537	0.0122	0	0
22	0	0	0.01074	0.00974	0.01882	0.00302	0	0	0.00063
23	0	0	0.00145	0.01277	0.00987	0.03153	0	0	0.00539
24	0	0	0.00109	0.04904	0.00199	0.04913	0.00147	0	0.00863
25	0	0	0.0177	0.0167	0	0.00013	0	0.00831	0.00291
26	0	0	0.01437	0.03091	0.00002	0.01721	0	0.00017	0.00205
27	0	0	0	0.00142	0	0.07422	0	0	0
28	0	0	0.00262	0.00222	0	0.06609	0.00109	0	0.00223
29	0	0	0	0.00909	0	0.0857	0	0	0.00038
30	0	0	0.00154	0.0146	0	0.09299	0.00181	0	0.00251
31	0	0	0.00404	0.00588	0.00034	0.00436	0	0	0.01456
32	0	0	0.00076	0.06023	0	0.01594	0	0	0.01038
33	0	0	0.004	0.03186	0.00005	0.02246	0	0.00005	0.02908
34	0	0	0.00271	0.03187	0	0.03959	0	0.00002	0.00814
35	0	0	0.00033	0.01488	0	0.08017	0.00164	0	0.01258
36	0	0	0.00041	0.0073	0	0.00756	0	0	0.0548
37	0	0	0.00649	0.0228	0	0.00782	0	0	0.0141
38	0	0	0.00064	0.04872	0	0.11375	0	0	0.0006
39	0	0	0.00007	0.00432	0	0.11805	0.00166	0	0.00382
40	0	0	0.00027	0.01702	0.00117	0.07196	0.00051	0	0.01452
41	0	0	0.01372	0.00869	0.00221	0.00069	0.00011	0	0.01908
42	0	0	0.00215	0.01208	0.02291	0.00117	0	0	0.00181
43	0	0	0	0.00415	0	0.09378	0	0	0

Truck Equivalency Factors – Truck Trailer (TT)

Commodity	Auto	Livestock	Bulk	Flatbed	Tank	Day Van	Reefer	Logging	Other
1	0	0	0.00236	0.09792	0	0.01831	0	0	0.00305
2	0	0	0.03312	0.00683	0.00121	0	0	0	0
3	0	0	0.01643	0.05417	0.00043	0.00965	0	0	0.00557
4	0	0	0.0024	0.0652	0.00229	0.01552	0	0	0.0026
5	0	0	0	0.01384	0	0	0.2178	0	0
6	0	0	0	0.06766	0	0.52158	0.02743	0	0
7	0	0	0	0.01609	0.00255	0.167	0	0	0.02212
8	0	0	0	0	0	0	0	0	0.09053
9	0	0	0	0	0	0	0	0	0
10	0	0	0.04803	0.00814	0.00047	0	0	0	0
11	0	0	0.03288	0.01714	0	0	0	0	0
12	0	0	0.03672	0.00355	0.00002	0	0	0	0.00136
13	0	0	0.04044	0.00133	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0
15	0	0	0.01956	0.02797	0	0	0	0	0
16	0	0	0.01529	0	0.01659	0	0	0	0
17	0	0	0	0.06287	0.0246	0	0	0	0
18	0	0	0.00047	0.02735	0.01863	0	0	0	0
19	0	0	0.00855	0	0.01411	0.03128	0	0	0
20	0	0	0	0	0.04058	0.0037	0	0	0
21	0	0	0	0	0	0	0	0	0
22	0	0	0.00321	0.02528	0.03006	0.03581	0	0	0.0015
23	0	0	0.00466	0.01526	0.00955	0.15924	0	0	0
24	0	0	0	0.25704	0	0	0	0	0
25	0	0	0.0087	0.00147	0	0	0	0.02241	0.01327
26	0	0	0.09538	0.03896	0	0.00107	0	0.00071	0.01724
27	0	0	0	0	0	0.06453	0	0	0
28	0	0	0	0	0	1.03919	0	0	0
29	0	0	0	0	0	1	0	0	0
30	0	0	0	0	0	0.43478	0	0	0
31	0	0	0.0194	0.01707	0	0	0	0	0.01178
32	0	0	0.00386	0.0495	0	0.00575	0	0	0.09511
33	0	0	0.02786	0.04576	0	0.125	0	0	0.04695
34	0	0	0.03163	0.03692	0	0.00129	0	0.00044	0.00078
35	0	0	0	0.13673	0	0.3511	0	0	0
36	0	0	0.02531	0.07947	0	0.03572	0	0	0.00623
37	0	0	0.02199	0.05941	0	0	0	0	0.00491
38	0	0	0	0.5	0	0	0	0	0
39	0	0	0.04346	0.02042	0	0.07936	0	0	0
40	0	0	0	0.06769	0	0.02033	0	0	0.02866
41	0	0	0.06573	0.02041	0	0	0	0	0.00178
42	0	0	0	0.00708	0.05154	0.00145	0	0	0
43	0	0	0	0	0	0.15382	0	0	0

Truck Equivalency Factors – Combination Semitrailer (CS)

Commodity	Auto	Livestock	Bulk	Flatbed	Tank	Day Van	Reefer	Logging	Other
1	0	0.02634	0.00087	0.00628	0.00046	0.00116	0.00061	0	0
2	0	0.00006	0.03127	0.00162	0.00124	0.00056	0.00004	0	0
3	0	0.0005	0.00636	0.0114	0.00062	0.00443	0.01419	0	0
4	0	0.00028	0.00873	0.00598	0.01261	0.00691	0.00257	0	0
5	0	0	0	0.00071	0	0.00449	0.03397	0	0
6	0	0	0	0	0.00389	0.03253	0.00495	0	0
7	0	0	0	0.00023	0.00373	0.01631	0.01912	0	0
8	0	0	0	0.00045	0.00021	0.04709	0.00137	0	0
9	0	0	0	0	0	0.0333	0.00725	0	0
10	0	0	0.012	0.02245	0.00221	0.00072	0	0	0
11	0	0	0.03032	0.00064	0.00423	0.00016	0	0	0
12	0	0	0.03249	0.00175	0.00032	0.0001	0	0.00002	0
13	0	0	0.01708	0.00104	0.01462	0.00124	0	0	0
14	0	0	0.02508	0.00955	0	0.00143	0	0	0
15	0	0	0.03109	0	0	0.00053	0	0	0
16	0	0	0.00055	0	0.03505	0	0	0	0
17	0	0	0	0	0.02918	0.00044	0	0	0
18	0	0	0.00005	0.00033	0.02883	0.00059	0	0	0
19	0	0	0.0003	0.00153	0.03075	0.00344	0	0	0
20	0	0	0.00004	0.00467	0.0281	0.0054	0	0	0
21	0	0	0	0	0	0.02969	0.01779	0	0
22	0	0	0.01042	0.00925	0.01569	0.00166	0.00025	0	0
23	0	0	0	0.0013	0.0266	0.00896	0.0003	0	0
24	0	0	0.00033	0.00511	0.00599	0.03019	0.00065	0	0
25	0	0	0.00172	0.00586	0	0.00117	0	0.02563	0
26	0	0	0.00529	0.02031	0	0.00905	0.0001	0.00109	0
27	0	0	0	0.00495	0	0.02996	0.00046	0	0
28	0	0	0	0.00031	0	0.03765	0.0005	0	0
29	0	0	0	0.00071	0	0.03842	0.00187	0	0
30	0	0	0	0.00096	0	0.03345	0.00069	0	0
31	0	0	0.00288	0.01613	0.01163	0.00331	0.00005	0.00024	0
32	0	0.00027	0.00144	0.03045	0.00017	0.00344	0.00018	0.00036	0
33	0	0	0.00048	0.02839	0.0001	0.00839	0	0	0
34	0	0.00009	0.0001	0.03017	0	0.00621	0.00018	0	0
35	0	0	0	0.00344	0	0.03622	0	0	0
36	0.01607	0	0.00038	0.00722	0	0.01871	0	0	0
37	0.0003	0	0.00022	0.0187	0	0.0167	0	0.00102	0
38	0	0	0	0.00625	0	0.03851	0	0	0
39	0	0	0	0.00233	0	0.03413	0.00171	0	0
40	0	0	0.00006	0.00374	0	0.03022	0.00159	0	0.00478
41	0	0	0.02326	0.00207	0.00785	0.00289	0.00013	0	0
42	0	0	0	0.0015	0.03183	0.00323	0	0	0
43	0	0	0	0.0009	0	0.04007	0.00082	0	0

Truck Equivalency Factors – Combination Double (DBL)

Commodity	Auto	Livestock	Bulk	Flatbed	Tank	Day Van	Reefer	Logging	Other
1	0	0.02963	0	0	0	0	0	0	0
2	0	0	0.02166	0.00434	0.0003	0	0	0	0
3	0	0	0.00363	0.02674	0.00057	0.00214	0	0	0
4	0	0	0.0114	0.01572	0.00081	0.00436	0	0	0
5	0	0	0	0	0	0	0.0625	0	0
6	0	0	0	0	0	0.05882	0	0	0
7	0	0	0	0.01003	0.00116	0.00546	0.01426	0	0
8	0	0	0	0	0	0	0.06061	0	0
9	0	0	0	0	0	0	0	0	0
10	0	0	0.01584	0	0.01808	0	0	0	0
11	0	0	0.02342	0	0	0	0	0	0
12	0	0	0.02123	0	0.00041	0	0	0	0
13	0	0	0.00567	0.00066	0.01929	0	0	0	0
14	0	0	0.00851	0	0.0177	0	0	0	0
15	0	0	0.01622	0	0.00158	0	0	0	0
16	0	0	0	0	0.03043	0	0	0	0
17	0	0	0	0	0.00862	0.03876	0	0	0
18	0	0	0	0	0.02204	0	0	0	0
19	0	0	0.01252	0	0.01619	0	0	0	0
20	0	0	0.00395	0.01861	0.00758	0	0	0	0
21	0	0	0	0	0	0	0	0	0
22	0	0	0.00749	0.02477	0.00117	0	0	0	0
23	0	0	0	0	0	0	0.02186	0	0
24	0	0	0	0.01595	0	0.05582	0	0	0
25	0	0	0	0	0	0	0	0.02353	0
26	0	0	0.00151	0.02389	0	0.00368	0	0	0
27	0	0	0	0	0	0	0	0	0
28	0	0	0	0.0413	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0.13793	0	0	0
31	0	0	0.00429	0.00411	0.01484	0	0	0	0
32	0	0	0.00232	0.01454	0	0	0	0.19078	0
33	0	0	0	0	0	0.0339	0	0	0
34	0	0	0	0.00878	0	0.03608	0	0	0
35	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0.06667	0	0	0
37	0	0	0	0.02857	0	0	0	0	0
38	0	0	0	0	0	0.11765	0	0	0
39	0	0	0	0	0	0.03463	0	0	0
40	0	0	0	0	0	0.05285	0	0	0
41	0	0	0.01953	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0.04439	0.00003	0	0

Truck Equivalency Factors – Combination Triple (TPT)

Commodity	Auto	Livestock	Bulk	Flatbed	Tank	Day Van	Reefer	Logging	Other
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0
12	0	0	0.02454	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0
31	0	0	0.02181	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0
34	0	0	0	0.01752	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0
37	0	0	0	0.01986	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0.02557	0	0	0

Appendix 4: Average Marginal Operational Cost from American Transportation Research Institute (ATRI)

Average Marginal Costs for years 2012-2016

Motor Carrier Costs per Mile	2012	2013	2014	2015	2016
Vehicle-based					
Fuel Costs	**$0.641**	**$0.65**	**$0.58**	**$0.40**	**$0.34**
Truck/Trailer Lease or Purchase Payments	$0.174	$0.16	$0.22	$0.23	$0.26
Repair & Maintenance	$0.138	$0.15	$0.16	$0.16	$0.17
Truck Insurance Premiums	**$0.063**	**$0.06**	**$0.07**	**$0.07**	**$0.08**
Permits and Licenses	$0.022	$0.03	$0.02	$0.02	$0.02
Tires	$0.044	$0.04	$0.04	$0.04	$0.04
Tolls	$0.019	$0.02	$0.02	$0.02	$0.02
Driver-based					
Driver Wages	$0.417	$0.44	$0.46	$0.50	$0.52
Driver Benefits	$0.116	$0.13	$0.13	$0.13	$0.16
Total	$1.633	$1.68	$1.70	$1.58	$1.59