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16. Abstract This report examines the potential for implementing new technologies to improve upon current practices for truck weight enforcement and commercial vehicle management in the United States. As truck freight traffic continues to grow, expansion of the existing network alone will not accommodate traffic flows. It will be necessary for government to introduce new technologies and legislation to maintain sufficient flow. Various technologies already in use throughout Europe and North America for weight and credential enforcement, toll collection, and fleet management offer potential for improved traffic flow and potential solutions to future congestion, financial constraints, and environmental concerns. This report provides a review of these technologies, and the potential benefits of implementing these systems in the US. The review focuses on the state of Texas, which is an important NAFTA corridor that currently utilizes traditional static, semi-portable, and portable scales and fixed price permits for commercial vehicle enforcement.			
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**POTENTIAL APPLICATION OF ITS TECHNOLOGIES
TO IMPROVE COMMERCIAL VEHICLE OPERATIONS,
ENFORCEMENT, AND MONITORING**

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ABSTRACT

This report examines the new technologies available to improve upon current practices for truck weight enforcement and commercial vehicle management and the potential for implementing these in the United States. As truck freight traffic continues to grow, expansion of the existing network alone will not accommodate traffic flows. It will be necessary for government to introduce new technologies and legislation to maintain sufficient flow. Various technologies already in use throughout Europe and North America for weight and credential enforcement and inspection, toll collection, and fleet management offer potential for improved traffic flow and potential solutions to future congestion, financial constraints, and environmental concerns. This report provides a review of these technologies, and the potential benefits of implementing these systems in the US. The review focuses on identifying potential benefits for the state of Texas, which is an important NAFTA corridor that currently utilizes traditional static, semi-portable, and portable scales and fixed price permits for commercial vehicle enforcement.

KEYWORDS: Commercial Vehicle Enforcement, Commercial Vehicle Operations (CVO), ITS, On-board Monitoring, On-Board Weighing, Toll Collection Technologies, Virtual Weigh Stations, Weigh-In-Motion (WIM)

EXECUTIVE SUMMARY

As international trade in the US continues to grow, particularly NAFTA trade with Canada and Mexico, commercial truck traffic will continue to increase. As the existing infrastructure approaches its capacity, environmental impacts and land use concerns will prevent highway expansion as a sole solution to increase freight capacity. The implementation of new ITS technologies to improve freight movement and enforcement will be necessary to ensure the safe and efficient flow of trade. The static weigh stations currently in use for weight enforcement throughout the US often contribute to delay, increase emissions, and create potential conflicts for trucks entering and exiting the station. Implementation of ITS technologies currently in use in the US and abroad for weight enforcement, fleet management, monitoring, and toll collection has the potential to largely eliminate these negative impacts by allowing weight enforcement at highway speeds in the main lanes of traffic.

Currently, the state of Texas relies mainly on manually operated static and semi-portable scales for weight enforcement. While weigh-in-motion (WIM) is utilized at two static weigh stations for pre-sorting and at 8 ports of entry (POE) along the Texas/Mexico border, a shortage of funding has prevented the implementation of additional ITS systems. Available funding also limits the hours of operation of static weighing facilities. The state of Texas offers various types of overweight and over-dimension permits, most of which are provided for a fixed cost. Implementation of additional ITS technologies has the potential to improve data collection, hours of operation, and efficiency of user charges while reducing negative impacts on congestion, safety, and the environment.

Weigh-in-Motion (WIM) and radio frequency identification (RFID) technologies are already widely used in the US for weigh station bypass by enrolled carriers. Several different types of WIM systems are in use or development with varying costs and accuracies. The three types already widely used in practice are bending beams, load cells, and piezoelectric sensors. Several other systems, including quartz sensors, fiber-optic sensors, and seismic scales are also in development or limited use. When combined with RFID systems, implementation of these systems for weigh station pre-clearance has already provided some improvements in efficiency in Texas and other US states; however, these improvements are generally limited to carriers

enrolled in existing pre-clearance programs, and generally provide no benefit to un-enrolled carriers.

Various tests have also been performed in US states to develop virtual weigh stations, which utilize WIM systems and video technologies for automatic vehicle identification (AVI) to identify and weigh all commercial vehicles traveling in main lanes of traffic. These studies have identified improvements in communication and video technologies necessary to achieve a useful system. Once these technological barriers are overcome, these virtual weigh station systems should provide significant improvements in delay, safety, and emissions by allowing all commercial vehicles to be identified and weighed while traveling in the main lanes of traffic at highway speeds. Although initial costs would be significant, installation of a virtual system is far less expensive than installation of a new static station. Virtual weigh stations could be operated for extended hours with far less personnel than static stations, allowing for increased enforcement and safety, as well as better data collection. This improved data could then be used for better infrastructure planning and monitoring, as well optimization of enforcement hours.

However, introduction of WIM and AVI systems alone will not achieve a truly safe and efficient truck freight network. The introduction of various monitoring and communications technologies currently in use abroad, as well as changes in the current fixed-cost permitting system, could potentially lead to further gains in safety and efficiency. Several European nations have implemented a distance-based heavy vehicle user fee (HVF). In Austria, dedicated short-range communications (DSRC) technologies are optionally used for automatic collection of this fee for trucks weighing more than 3.5 tons on the mainline of toll roads. The charge per kilometer varies depending on distance traveled and truck category based on number of axles. In Switzerland, domestic vehicles are required to and foreign vehicles have the option to be equipped with an on-board unit (OBU) that includes both DSRC and GPS antennae as well as a connection to a digital tachograph. While DSRC is used only at border crossings, HVF data for distance traveled on all public roads by trucks greater than 3.5 tons is collected by manual or electronic transmission of digital tachograph data to road authorities. GPS distance data is also collected, but is used only to check for inconsistencies in tachograph data. In Switzerland, the fee is based on distance traveled, highest allowable weight, and emissions class. In Germany, a completely GPS based system for distance data collection on toll roads has been tested, and is

ready for full scale implementation in January 2005. This fee applies only to trucks weighing more than 12 tons, and is based on distance traveled, number of axles, and emissions class. All of these systems were implemented with a goal to not only raise revenues for road improvement and maintenance, but also to encourage efficient loading and consideration of alternative modes of transportation.

The European Union (EU) as a whole has also taken steps to improve truck operations. In the late 1980s, the EU mandated the use of mechanical tachographs for monitoring driver speeds and hours on all buses and commercial vehicles in its member states. In 1998, new legislation was passed which mandated the use of digital tachographs, which are more tamper-proof, by August 2004. An extension has since been passed, pushing this deadline to August 2005 to allow industry to equip itself with the new tachographs. In addition, Tachonet, a telematic network for sharing tachograph data between member states is also in development to improve enforcement on vehicles traveling through multiple member states. Most recently, anticipating the completion of Galileo, Europe's new global navigation satellite system (GNSS), the European Commission has passed a directive requiring all automatic toll collection systems in the union to be GNSS based and fully interoperable by 2012.

The Saskatchewan Rural Partnership Haul Program also utilizes GNSS based monitoring as part of its program. Through a public private partnership with the Saskatchewan Department of Highways and Transportation (SDHT), carriers are permitted to use overweight and over-dimensional trucks on certain routes if they agree to install road-friendly technologies on their vehicles and share cost savings with road the road authorities. Vehicles are equipped with a data collecting on-board unit that includes GPS, central tire inflation (CTI), and air-spring suspension weight sensors. Data is transmitted to the central administration system through a cellular network. Once received and processed, this data can be accessed by both carriers and authorities through a remote query system. By providing an innovative profit sharing scheme, this program has gained acceptance by and provided profits for both carriers and authorities.

Introduction of these monitoring, toll collection, and on-board weighing technologies in the US, combined with introduction of new user based fees such as a distance tax, could achieve considerable gains in financial efficiency by allowing for more exact charging for use.

Implementation of these technologies could also minimize or eliminate the need for installation and maintenance of roadside infrastructure by including all necessary weighing and monitoring technologies on-board. Use of GPS tracking and digital tachography could significantly increase the availability of data for infrastructure planning and monitoring. In addition, the use of digital tachographs for monitoring of driver hours, speeds, and rest periods could considerably improve vehicle safety by allowing for better enforcement of violators.

However, it is unlikely that these on-board technologies would be easily accepted by carriers in the US, where privacy is highly valued. In order to determine the true feasibility of applying these on-board technologies, a complete study of institutional barriers and privacy concerns must be completed. The study should examine the implementation of technologies currently in use and examine what institutional barriers existed and how they were overcome. The study should also examine both visionary legislative changes such as those implemented in the EU and innovative solutions such as the public private partnership introduced in Saskatchewan as a potential means to overcoming these barriers.

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION.....1
 Past Studies.....2
CHAPTER 2. CURRENT REGULATION IN TEXAS.....5
 Weight Enforcement5
 Permitting6
 Inadequacies6
 Funding Issues.....6
 Poor Data Availability7
 Environmental Impacts.....7
 Compromised Safety, Security, and Efficiency7
CHAPTER 3. WEIGHING AND INSPECTION TECHNOLOGIES9
 Weigh-in-Motion (WIM) Systems.....9
 Bending Beam.....9
 Single Load Cells10
 Piezoelectric (Ceramic) Sensors.....10
 Quartz Sensors.....11
 Fiber Optic Sensors11
 Seismic Scales.....11
 Weigh Station Pre-Clearance Systems.....12
 Virtual Weigh Stations.....14
CHAPTER 4. POTENTIAL BENEFITS OF APPLYING WEIGHING TECHNOLOGIES FOR
COMMERCIAL VEHICLE ENFORCEMENT.....17
 Financial Improvements.....17
 Safety Improvements17
 Data Improvements.....17
 Environmental Benefits.....18

CHAPTER 5. BEYOND WEIGHING TECHNOLOGIES.....	19
User Fees	19
Austrian GO Box.....	19
Swiss Heavy Vehicle Fee.....	20
German Toll Collect	21
European Interoperability	22
Tachographs.....	22
Tachonet.....	23
Toll Collection Interoperability.....	23
Infrastructure Management	23
Saskatchewan Rural Partnership Haul Program	24
Vehicle Inspection	25
Infrared Brake Screening.....	25
Future Applications.....	26
CHAPTER 6. POTENTIAL BENEFITS OF APPLYING TOLLING AND MONITORING SYSTEMS FOR COMMERCIAL VEHICLE ENFORCEMENT	27
Data Improvements	27
Financial Improvements	27
Environmental Benefits.....	28
CHAPTER 7. CONCLUSION.....	29
Future Work.....	30
REFERENCES.....	31

CHAPTER 1. INTRODUCTION

According to the Transportation Research Board's (TRB) Committee for the Study of Freight Capacity for the Next Century, highway freight traffic will increase by 40 percent by the year 2020 due to growth of domestic and international trade (1). As further highway expansion becomes both increasingly expensive and environmentally impossible, states will need to increase the capacity of the current network to accommodate this traffic growth. Existing weigh station systems, especially in urban areas and at border crossings, contribute to congestion, accidents, and emissions. Various technologies currently in use in North America and Europe for weight and credential enforcement, toll collection, and fleet management offer potential for improved traffic flow, reduction of accidents, congestion, and emissions, and improved data collection capabilities. Available technologies with the potential to improve truck freight management and operations include weigh-in-motion (WIM), automatic vehicle identification (AVI), communications, and remote and on-board monitoring systems. In addition to the introduction of new technologies, changes in policy concerning infrastructure management, highway user costs, and highway user regulations will likely be necessary to achieve efficient use of the existing or future network (1).

As freight traffic continues to increase, new technologies will need to be implemented to increase road capacities (1). As a primary NAFTA trade corridor, the state of Texas will likely see significant traffic growth rates. Currently, the state of Texas employs ITS technologies for weight enforcement only at border crossings and two internal weigh stations. While ports of entry (POE) use WIM and AVI to expedite traffic crossing the border and weigh stations at Devine and New Waverly utilize WIM for preclearance, enforcement elsewhere in the state relies on traditional static, semi-portable, and portable scales. In order to accommodate oversized vehicles, the Texas Department of Transportation (TxDOT) issues various types of oversize and overweight permits, most of which have fixed costs. These permit fees, in addition to motor fuel taxes, are used to fund highway maintenance and improvement projects. Using the state of Texas as an example for potential improvement, this report examines new technologies currently in use for freight operations, the policies required to employ these technologies, and the potential benefits of state implementation.

PAST STUDIES

Although traditional static weigh stations are widely viewed as having significant negative impacts on the capacity and safety of highways on which they are located, very few studies have been performed to quantify these impacts. In 1999, a study was performed in Illinois to measure the delay and safety impacts of a traditional weigh station (2). Since the mid-1990s, various studies have examined the changes in safety and delay resulting from installation of WIM and AVI systems for pre-clearance. A follow up to the initial study of the traditional weigh station in Illinois was performed to measure the changes in safety and delay after installation of a WIM and AVI system for pre-sorting (3). The Advantage I-75 project examined time savings for carriers utilizing AVI for automatic clearance at weigh stations, as well as measured fuel savings (4). Most recently, a study performed in Taiwan examined the integration of AVI systems used for electronic toll collection with WIM systems for weigh station bypass (5).

In recent years, several studies have examined the application of WIM and video monitoring systems as virtual weigh stations operating in the main lanes of highways. A study performed in Indiana identified benefits in the efficiency of identifying overweight trucks for weighing, as well as measured the accuracy and precision of a virtual weigh station in operation to identify areas of improvement needed for full scale operation (6). A similar study performed in Kentucky also identified additional areas of improvement in video and communications technologies needed for full scale implementation of a virtual weigh station (7). A study performed in Saskatoon, Canada focused on the potential application of a WIM/video surveillance system to quantify the effects of overweight vehicles in an urban environment and to identify potential solutions to improve enforcement to reduce these impacts (8).

Several states have examined additional benefits of using WIM systems, particularly for data collection. The state of California utilizes WIM data as an essential tool for pavement management as well as highway monitoring (9). The state of Montana performed a study examining the use of WIM data to optimize enforcement and minimize the impacts of overweight vehicles on infrastructure (10). Oregon used WIM to study the evasion behavior of trucks on secondary roads bypassing a weigh station, which while unable to identify any

significant evasion behavior did conclude that those enrolled in Greenlight, the state's automatic clearance system, were more likely to be complaint (11).

In 1999, a study examined the potential application of WIM and AVI for weight enforcement of NAFTA traffic at the Texas/Mexico border (12). In addition to identifying these potential and existing applications of WIM and AVI in the state of Texas, this report will also examine the potential integration of additional monitoring technologies not currently in use in the US for weight enforcement. Considering the results of these previous studies, this report will examine the potential benefits and feasibility of applying current monitoring and toll collection technologies, as well as WIM and AVI systems for commercial vehicle management and enforcement throughout the state of Texas.

CHAPTER 2. CURRENT REGULATION IN TEXAS

WEIGHT ENFORCEMENT

The state of Texas currently operates four different types of scales for weight enforcement: permanent scales, semi-portable scales, portable scales, and Weigh-in-Motion (WIM) scales. In high traffic areas, the Department of Public Safety (DPS) operates 49 permanent scales, 26 of which are located on interstates (13). Since there is insufficient funding and manpower to operate these permanent stations on a full time basis, these scales are operated with random hours. Each scale requires between three and ten troopers for operation. Eleven of these permanent scales are required to be operated at least 40 hours per week.

DPS License and Weight officers also operate semi-portable scales at weigh stations not equipped with permanent scales and on the shoulders of roadways with appropriate space for safe stoppage. These 33 semi-portable scales are operated in minimum two hour shifts by three or more troopers, ideally for 32 hours per week. Each License and Weight Vehicle is also equipped with a portable scale for random utilization by DPS enforcement officers.

Texas currently operates two WIM scales for weigh station pre-clearance. These scales are located off the main lines of I-35 in Devine and I-45 near New Waverly. Temporary WIM scales are also in operation at eight ports of entry (POE) on the Texas/Mexico Border. These scales are operated for the same hours as the POEs. These temporary scales will be replaced by permanent scales currently under design and construction. These permanent scales should be operational by 2005.

Scales may be operated by either the state or the county. DPS provides training for purchasing and operating scales to counties who request scales (Mark Rogers, December 2003, personal communications). Each county also reaches an "Individual Memorandum of Understanding" defining the roles of the state and the county in scale operation. All violations are filed in the municipal courts of the site of violation; however, copies of each violation are also submitted to the state comptroller. In addition, troopers are required to file a weekly activity report detailing each truck searched.

PERMITTING

The permissible weight for vehicles in Texas varies from 40,000 to 80,000 lbs for vehicles with two to seven axles (13). There are several types of overweight and over-dimension permits available from TxDOT (14). Single-trip permits include general point to point permits, mileage permits, super heavy vehicle permits, and manufactured housing, portable building, and oil well servicing permits. General single trip permit rates vary according to weight category and include both highway maintenance and permit fees. Mileage permits charge per vehicle mile traveled. Super heavy vehicle permits include highway maintenance and permit fees, as well as an additional charge for bridge analysis. All other single trip permits have fixed costs. Annual or quarterly specialty permits include 30/60/90 day over-width/over-length permits, vehicle and company specific annual over-length/over-width envelope permits, annual over-axle and over-gross weight permits and various other load specific specialty permits, all of which have fixed costs. TxDOT is also a member of the "Western Regional Agreement for the Issuance of Permits for Oversize and Overweight Vehicles Involved in Interstate Travel," providing regional permits for use in several neighboring states as well as Texas. Carriers can obtain TxDOT permits by applying electronically or by submitting paper applications.

INADEQUACIES

Funding Issues

Although federal funding is available for operations at US/Mexico border crossings, Texas suffers from a lack of available funding for operations elsewhere in the state. In 2003, the License and Weight Service (L&W) was allocated a total budget of \$24,683,602. A total of \$21,732,805, or 88 percent of the total budget, was allocated to enforcement personnel. The program had a total of 670 employees, including 400 troopers, 73 L&W supervisors, and 197 non-commissioned employees to perform inspections, site maintenance, and compliance reviews (13). A lack of additional funding has prevented the state from implementing roadside screening capabilities to achieve Commercial Vehicle Information Systems and Networks (CVISN) Level 1 architecture. Although mainline screening is prepared to go operational at six locations, there is no funding available for implementation (Mark Rogers, December 2004, personal communications). The lack of available resources also prevents permanent weigh stations from being operated on a full time basis.

Poor Data Availability

The random hours of operation of all types of scales do not allow the state to accurately characterize truck traffic or determine the actual number or overweight violations. In addition, the inefficient practices of filing weekly activity reports and prosecuting violators municipally leaves potential for errors in compiling accurate data. This lack of data accuracy and availability hinders the state's ability to calculate the real impacts of violators on its infrastructure and to plan appropriately for the future.

Environmental Impacts

The continued use of static weigh stations has several negative environmental impacts. Trucks forced to accelerate and decelerate to enter weigh stations and to wait in queues for inspection release increased levels of hydrocarbons into the atmosphere and waste fuel. In addition, land may not be available due to neighboring land use or wetlands for construction of a static station at locations where traffic necessitates weight enforcement.

Compromised Safety, Security, and Efficiency

The current use of offline weigh stations operated at random hours does not achieve the safety, security, or efficiency that would be possible using ITS technologies on the mainline. Although no data is available for absolute proof, the DPS is concerned about potential conflicts between commercial vehicles and other vehicles on the roadway due to acceleration, deceleration, and weaving at weighing facilities (Mark Rogers, December 2004, personal communications). The random operation of inspection facilities also poses a security concern, as trucks passing a closed station are neither weighed nor inspected. Finally, the random operation and potential delays at weigh stations prevent carriers from efficient trip planning and use of time and fuel.

CHAPTER 3. WEIGHING AND INSPECTION TECHNOLOGIES

WEIGH-IN-MOTION (WIM) SYSTEMS

The American Society for Testing and Materials (ASTM) defines WIM as “the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicle (15).” ASTM defines four types of WIM systems for varying uses using 3 three different technologies: bending beams, piezoelectric sensors, and single load cells (16). While all three types are used for commercial vehicle weight enforcement, ASTM recommends only the use of Load Cells and Bending Plates for commercial weight enforcement. In addition to these WIM systems, three other measurement technologies are currently in development. Quartz sensors have been tested and applied in limited applications. Fiber-optic sensors and Seismic WIM are also in development and testing stages, but have yet to be applied commercially.

Bending Beam

A bending beam plate consists of a single piece of metal with no welding or bolting (17). Attached strain gauges measure the deflection in the beam when a truck crosses it. For most efficient operation, staggered scales should be placed in the main line of the roadway to weigh both the left and right side of each axle, and the overall axle weight should be calculated as the sum of the axles. Bending beams exhibit an approximate absolute error of 10% at a 95% conformity rate at highway speeds (15). However, the installation of multiple plates may reduce 95th percentile error to as little as 5% (18).

Initial equipment for a bending beam system costs about \$8,000 per lane, and installation costs about \$13,500 per lane (19). Bending beams may be installed in concrete roads in one day by shallow excavation and anchoring of the plates using anchoring bars and epoxy. On asphalt or shallow concrete roads, installation requires a 3 day process of roadway cut and excavation to form a pit for a concrete foundation followed by casting of the scales into the concrete foundation. The annual life cycle cost for a bending beam system over a 12 year life span is approximately \$6,400.

Single Load Cells

A single load cell system should consist of two independent platforms located adjacent to one another in a single travel lane, with each platform bolted to a scale module (17). The adjacent placement allows all wheel sets on an axle to be weighed simultaneously, and together the platforms should cover the width of a travel lane. Again, the axle weight is calculated as the sum of the left and right wheels. Each scale includes a single hydraulic loading cell, and load transfer torque tubes to transfer the load to the load cell, regardless of the location of the tires on the platform. Single load cells provide the least probability of error at highway speeds, with approximate error of 6% at a 95% level of conformity (15).

Initial equipment costs \$39,000 per lane, and installation costs about \$20,800 per lane. Single load cells have an average estimated cost per lane over a 12 year life span of \$6,200 (19). Again, installation requires a 3 day process of roadway cut and excavation, concrete vault construction, and setting and casting of frames into the concrete.

Piezoelectric (Ceramic) Sensors

Unlike the other scales which measure only vertical force, piezoelectric sensors measure the total energy transferred to the pavement by a passing truck (18). The force measured is also affected by acceleration and deceleration of the trucks. As a result, piezoelectric scales exhibit higher absolute errors of about 15% at highway speeds and a 95% conformity rate (15). Like bending beam systems, the installation of multiple sensors may reduce errors by as much as 50% (18). Piezoelectric sensors are typically ceramic, and are often encased in aluminum to reduce effects of lateral forces (20). In addition, piezoelectric scales generally measure axle weights, unlike load cells and bending beams which measure individual wheel weights.

Installation of piezo systems require only small cuts in the roadway for placement and setting of sensors using fast curing grout (19). The installation process is faster, taking less than a day, and less expensive, at only about \$6,500 per lane, than installation of other WIM systems. Equipment and life cycle costs of about \$2,500 and \$4,750 per lane are also less expensive than other common WIM systems. Initial equipment costs \$2,500 per lane, and installation costs about \$6,500 per lane.

Quartz Sensors

In order to address some of the deficiencies of traditional piezoelectric sensors, quartz piezoelectric sensors have been developed. Unlike the ceramics used in most piezo sensors, quartz sensors provide a linear output and demonstrate stability over long periods of time and various temperatures (20). In addition, quartz is an extremely stiff material that deflects very little; therefore it provides a high frequency response to a truck passage, and is good for fast changing measurements. Under normal conditions, quartz sensors have a general error of about +/- 5% at a 95% confidence interval (21). However, the error of the sensor is highly sensitive to the flatness of the pavement surrounding it. In tests performed on 2 straight, smooth off-ramps in New Hampshire at trucks speeds of approximately 45 mph, the sensors exhibited a maximum error of only 2%.

Fiber Optic Sensors

Although not yet in use commercially, several types of fiber-optic sensors are also in development for WIM. These include fiber grating sensors (22) and forward time division multiplexing (FTDM) dual-core sensors (23). Fiber-optic sensors have lower power requirements and are less sensitive to harsh environments than traditional sensors (24). As a result, fiber-optics has the potential to create a highly accurate sensor for about the same cost as a traditional piezoelectric sensor.

Seismic Scales

Another type of scale that has been tested for research, but is not yet in commercial use is a seismic WIM system (SWIM) (25). This system uses geophones and speed measurement devices to measure the speed and the strength and spectrum of the seismic signal from passing truck. These measurements can then be used to derive the weight of the truck. Studies have found that for this purpose, the transverse component of force from the seismic signal is most useful. The tests, performed in Florida and Alabama, have also found that the system is most useful in asphalt pavements. This system is still in development, as its results are dependent on truck, pavement, and soil properties, and it is highly sensitive to temperature, moisture, and wind.

Actual performance of any WIM system depends on its environmental conditions (15). High quality, fully functioning sensors used in a less than ideal environment may not provide accurate data. The typical life of a WIM system is about 15 years, a length determined more by pavement conditions than scale life (Brian Taylor, February 2004, personal communications).

WEIGH STATION PRE-CLEARANCE SYSTEMS

In the United States, WIM is generally used for weigh station pre-clearance. Many of these systems combine WIM and radio frequency identification (RFID) technologies for bypass of permanent weighing and inspection facilities. The 3 major pre-clearance systems in the US utilize radio frequency transponders to identify vehicles. An antenna, generally located approximately one mile before a weigh station, sends a signal to a transponder located in the truck, triggering the transponder to send its identifying data to a remotely located computer (26). In addition, weight data is transmitted from WIM scales located in the main line of the roadway and a height detector verifies that a truck is not over its height limit. The computer then verifies the credentials for the truck and ensures that it is within its weight and height requirements. The computer then sends a signal back to the truck's transponder instructing the driver to either bypass or pull into the weigh station.

RFID transponders are an easy and accurate device for identifying a vehicle. However, they are currently not as useful as other AVI systems, as they can only identify vehicles enrolled in existing systems. Although enrollment provides many benefits for carriers, including improved speed, fuel economy, and safety, it is unlikely that habitually offending carriers would voluntarily enroll themselves in a vehicle identification system. The largest pre-clearance system in the US is the HELP PrePass system, a public-private partnership currently operational in 24 states. PrePass collects a monthly user fee for enrolled trucks to maintain and operate its system. This monthly fee allows HELP to more accurately project revenues than its previous pay per pass system, and it improves system efficiency by discouraging carriers from keeping unused transponders (James Gentner, February 2004, personal communications). PrePass members must be pre-certified, and their safety records and credentials are continuously verified by state agencies (27). Texas would like to be able to use WIM and AVI data for various

purposes; therefore, the state does not currently participate in the PrePass system (Mark Rogers, December 2004, personal communications).

While its technologies are the same, PrePass is not currently integrated with the other systems in the US because of operational differences. NorPass and Oregon Greenlight, the other main US systems, depend on government funding for their operation and maintenance (28). The only user costs for these systems are the price of the transponders; however, Oregon even distributes a number of transponders free of charge to Oregon based carriers (26). PrePass transponders may be enrolled in the NorPass and Greenlight systems; however, Norpass and Greenlight users must join PrePass in order to bypass PrePass stations.

In order for RFID identification to become useful for independent virtual weigh stations, all trucks would have to be required to have RFID tags. While this does not appear to be happening in the near future, it is certainly a possibility as safety, security, and costs – all issues that can be improved with better weight enforcement – are growing concerns in the US.

AVI technologies are in use to ease congestion and improve efficiency at US/Mexico border crossings in Texas. The US Customs and Border Patrol's Free and Secure Trade (FAST) program allows expedited clearance at several border crossings for carriers and importers enrolled in the Customs Trade Partnership Against Terrorism (C-TPAT) (29). In order to participate, carriers and importers must enroll and ensure the use of high security mechanical seals on US bound shipments. Drivers must apply for and be cleared for a FAST license. Enrolled vehicles may then use dedicated lanes, face a reduced number of examinations, and take advantage of expedited cargo release by 2 methods, transponder and barcode. Dedicated lanes are available at El-Paso, Laredo, Hidalgo, and Brownsville in Texas.

However, the technologies used for the FAST program have quickly become outdated and are not interoperable with the other popular pre-clearance systems. Although Texas does not currently participate in any of these other systems, it is important when planning for the future that the state consider interoperability with other American systems. This is particularly important for NAFTA trade since Texas provides a gateway to Mexico. I-35 and I-10, primary North-South and West-East NAFTA trade corridors, both terminate at US/Mexico border crossings.

VIRTUAL WEIGH STATIONS

Since RFID technologies can only be used at present to identify enrolled carriers, several states and provincial governments have been testing the use of optical character recognition (OCR) technologies with WIM to create virtual weigh stations. These systems utilize high resolution cameras to identify vehicles. As vehicles pass a virtual weigh station, the camera is triggered, either by the WIM or by other sensors. The camera then captures an image of identifying numbers on a truck, usually the USDOT identification numbers required on the truck or its license plate. The high resolution image is then compressed and transferred, in addition to any WIM data, to a system which reads the captured ID numbers and compares them with an existing database to check credentials. Operating these systems in the mainline of a roadway can eliminate the need for off-road weigh stations. They can also be located on secondary roadways to catch trucks evading static stations. Unlike the RFID systems, these systems can be used to check credentials for all trucks, not just enrolled carriers.

However, there are definite concerns about the accuracy of existing OCR systems. The Kentucky DOT performed tests on a system architecture consisting of two loops for triggering of a fast shutter, high resolution camera combined with WIM scales. While 92% of system triggers represented actual trucks passes, only 78% of those valid triggers capture the truck's USDOT numbers (30). Of those capture, only 44% were readable, resulting in only a 34% success rate in capturing readable USDOT numbers for trucks. Factors contributing to inability of the system to read the numbers included camera placement, truck speed, lighting conditions, and inconsistencies of the size, font, color, and contrast of the USDOT numbers on the trucks (7). Uniformity of USDOT numbers would likely increase the accuracy of the system. In addition, researchers faced problems finding a reliable, efficient, and affordable communications network. After considering dial-up and satellite modems, both of which were too slow for transmission of data to authorities, researchers chose to use a cable modem that allowed data to be correlated, compiled, and sent in under two minutes.

A similar study was performed in Saskatoon, Canada, where 2 main lanes were equipped with WIM and video license plate readers (8). This study also used cable modems for data transmission from the devices and wireless communications to transmit data to police laptops. The study produced several interesting conclusions. The study found both positive and negative

impacts of an urban location of the system, as the study could take advantage of WiFi capabilities likely unavailable in more rural areas, but some devices were also vandalized, a problem not found in the Kentucky study. After collecting one and a half years worth of data, researchers concluded that the majority of pavement damage was caused by two-axle trucks. However, somewhat discouragingly, the study also concluded that more enforcement did not lead to a reduction in this trend.

CHAPTER 4. POTENTIAL BENEFITS OF APPLYING WEIGHING TECHNOLOGIES FOR COMMERCIAL VEHICLE ENFORCEMENT

FINANCIAL IMPROVEMENTS

In the long term, implementation of additional WIM systems, as well as introduction of new RFID and OCR vehicle identification systems, would likely have positive financial impacts in Texas. Although initial equipment and installation costs may be burdensome at present, the long term cost savings would likely outweigh initial capital costs. The use of WIM and automatic vehicle identification systems would likely reduce the number of employees required for effective enforcement by allowing multiple locations to be monitored using remote monitoring systems. By reducing manpower required for enforcement, the DPS could potentially operate weigh stations for longer hours if not on a full time basis. In addition, due to high costs of land, the cost of constructing a virtual weigh station on existing right-of way is usually less expensive than constructing a permanent-static weigh station.

SAFETY IMPROVEMENTS

The use of WIM and AVI technologies on the roadway would likely improve safety both for commercial vehicles and other vehicles traveling on the shared roadway. By eliminating the need for acceleration, deceleration, and weaving to enter static weigh stations or pull over to the shoulder, the use of mainline weighing technologies reduces the potential for collision. This reduced number of collisions not only improves safety but also increases capacity. However, the use of mainline technologies does pose a new safety concern, as enforcement officers do lose personal contact with drivers. However, this concern can likely be addressed by the use of on-board monitoring systems discussed later in this report.

DATA IMPROVEMENTS

Successful operation of WIM and AVI systems to increase hours of operation and collect more and better quality data could be useful for both traffic and infrastructure planning. In Florida, the Department of Transportation (FDOT) uses WIM data for both planning and pavement monitoring (Michael Ackeridge, February 2004, personal communications). The state

of California utilizes IM data for both pavement management and highway monitoring (9). In Montana, WIM data was used to optimize hours of enforcement and improve rates of identifying violators (10). Better data could allow TxDOT to more accurately measure the impact of commercial vehicles on the state's infrastructure. This data could eventually be used to adjust permit costs or possibly to eventually implement cost-based user fees such as a distance related toll. However, in order to achieve optimal planning capabilities using data collected by AVI technologies, all commercial vehicles would need to be equipped with RFID transponders. In order to achieve 100 percent participation, the state would likely need to pass legislation requiring the use of RFID tags. It is unlikely that such legislation would pass, as carriers would most likely view the mandatory tags as a privacy invasion.

ENVIRONMENTAL BENEFITS

The use of weighing and identification technologies in the mainline of the roadway may not only lead to cost and efficiency savings, but can also produce environmental benefits. By eliminating stopping and idling, the use of these technologies will reduce hydrocarbon emissions. A study performed by Iowa State also found that bypassing weigh stations led to measurable fuel savings (4). However, researchers were unable to quantify exact fuel savings, as the amounts varied according to the number of stations bypassed and the nature of the stations.

CHAPTER 5. BEYOND WEIGHING TECHNOLOGIES

While implementation of these WIM and AVI technologies may improve the safety and efficiency of commercial vehicle operations, these systems alone will not optimize the use of existing and planned facilities. TRB's Committee for the Study of Freight Capacity for the Next Century concluded that the most effective way to control costs of accommodating future traffic is by coordinating practices in all areas of highway management, including infrastructure design and management, highway user regulations, and highway user fees (1). While implementation of AVI technologies and WIM may greatly improve the availability of data to determine the real impacts of vehicle weights on infrastructure, resulting adjustments to existing permitting systems may not be the most efficient means of controlling truck shipping costs for either carriers or authorities. The TRB Committee for the Study of the Regulation of Weights, Lengths, and Widths of Motor Vehicles also recognized that cost-based user fees could possibly supplement or partially replace size and weight regulation to produce more efficient control (31).

Several European nations have already implemented distance based heavy vehicle taxes for commercial vehicles traveling on their roadways. The technologies utilized, classification systems, and tariff structures all vary greatly between the countries; however, the government of the European Union is already looking to implement standards to combine these individual systems into an interoperable Europe-wide network.

USER FEES

Austrian GO Box

In Austria, Autostrade EUROPPASS began operating a dedicated short range communications (DSRC) based toll collection system for the Austrian government in January of 2004 (32). Toll rates ranging from .130 to .273 euro are based on distance traveled and four vehicle categories based on number of axles, and tolls are charged for both empty and loaded vehicles (33). The tag utilized by the system is called a Vehicle GO Box. It stores information about the license plate, basic vehicle category, and mode of payment for the truck. Both pre-pay and post-pay options are available. The tags are available at 230 points of sale for a cost of 5 euro. The system includes a total of 120 gantries for enforcement, including 100 stationary and 20 portable gantries. It also includes 420 gantries for toll charging, and 30 vehicles and 100

officers for manual enforcement. The gantries receive DSRC transmissions of data to ensure that a truck is appropriately registered.

Austrian authorities had three goals in mind when implementing this system (34). By implementing the distance based tax, the government hoped to raise revenues to finance maintenance and improvement of the motorway network. In addition, the government hoped to slow recent growth of road freight-traffic and encourage the use of other transportation modes. Finally, authorities hoped to improve efficient use of the system by forcing carriers to reduce empty trips and to fully utilize load capacities.

Swiss Heavy Vehicle Fee

In January of 2001, the Swiss Customs Authority (SCA) began directly administering a distance based heavy vehicle fee for vehicles weighing more than 3.5 tons traveling on all public roads in Switzerland (35). The tax is based on distance traveled, highest permissible weight, and emissions class of the commercial vehicle. Domestic vehicles are required to be equipped with an OBU, provided free of charge, that includes a chipcard reader, DSRC and GPS antennae, keyboard, display, and connection to a digital tachograph. At border crossings, DSRC communications activate and deactivate the OBU's distance counting mechanism. The OBU records all events from the tachograph in a logfile; however the OBU does not calculate the fee on-board. Payment of the fee requires drivers to send data to customs by mail or internet for a monthly read-out. The SCA then assesses the data and invoices the owner (36). Although it has relatively low accuracy (errors of +/- 4 percent) the tachograph data is legally recognized. Global Positioning System (GPS) distance data, while possibly more accurate, is not legally recognized but is used to check for inconsistencies in tachograph data. Foreign vehicles may also opt to use an OBU; however, they are not required to do so. Carriers who seldom use Swiss roads may choose to instead receive an ID card at the border for use at self service machines where a driver may manually enter odometer data and choose a payment option. Enforcement stations are equipped with OCR license plate readers to identify foreign vehicles without OBUs.

The Swiss Authorities, like their counterparts in Austria, hoped that the tax would encourage carriers to improve fleet management and possibly shift some freight to other modes.

By including emissions criteria in determination of the toll rate, the Swiss also hoped to encourage carriers to replace high emissions vehicles and utilize more specialized trucks (36).

German Toll Collect

On January 1, 2005, Toll Collect GmbH plans to begin full operation of a GPS based toll collection system for the German Federal Government (37). The system will calculate a distance based toll for trucks weighing more than 12 tons traveling on German toll roads. The toll rates are based on distance traveled, number of axles, and emissions class, and the fees range from .09 to .14 euro per km. Each user will be billed monthly, either by direct debit, credit card, or fuel card. Like the Swiss system, automatic and manual log-on options are available. Carriers choosing the automatic log-on option must use trucks equipped with an OBU available free from Toll Collect. The OBU uses GPS technologies to recognize toll roads and determine distance traveled. The OBU then calculates the required toll payment using pre-set vehicle and rate information. DSRC communications are used to ensure payment of the tolls. Although implementation of the system was initially delayed due to the questionable accuracy of the GPS data, independent tests performed using 41 volunteer domestic and foreign vehicles in May of 2005 found that 99.2 percent of roadway travel was accurately recorded (38). Users may also choose from two manual log-on options: internet log-on, which requires system registration, and log-on at toll station terminals. Both of these options require the user to manually enter intended routes.

The enforcement system includes 300 stationary control bridges, which are outfitted with cameras to check registration numbers of vehicles without OBUs and DSRC technologies to receive transmissions from vehicles using OBUs. If these checks find that a toll has not been paid or route information is incorrect, information is passed by DSRC to stationary enforcement officers within ten seconds. The system also includes 535 mobile enforcement officers whose vehicles are equipped with DSRC to check user log-on and PCs connected to headquarters by a global system for mobile communication (GSM) connection to review manual route data. These manual enforcement officers may also perform random checks.

European Interoperability

While these systems are very different in technology and administration, recent European Union policies have attempted to bring about both technological interoperability and administrative similarity between European systems. Short term EU goals include the introduction of digital tachographs for commercial vehicle monitoring and development of a network to share the data collected by these tachographs among EU member states. Eventually, the EU hopes to implement a fully interoperable Europe-wide GNSS based toll collection network.

Tachographs. In the late 1980s, the European Union passed legislation requiring all commercial vehicles operating in its member states to be equipped with tachographs, which are devices that record drivers' hours and periods of rest (39). New legislation was passed in 1998, requiring all new vehicles in the EU to be equipped with digital tachographs by August 5, 2004; however, due to the inability of industry to appropriately equip itself for installation of the new tachographs by the required deadline, this date was pushed back to August 5, 2005 (40). This legislation also required all vehicles of non-EU signatories of the "European Agreement on the Work of Crews of Vehicles Engaged in International Transport (AETR)" to be equipped with digital tachographs by 2008 (39).

The new digital tachographs are much more complex than previously used mechanical and analog systems. The recording unit consists of the tachograph and a driver card. In addition to vehicle, tachograph, and driver identification information, both the tachograph and driver card record manually entered start and end location data, distance traveled, and detailed speed information. The tachograph records all driving time including episode and total data, rest periods, driver availability, work, and faults. The driver card records driving periods when inserted into the tachograph and records manually entered rest, availability, and work data. Each driver receives only one card which is issued by his or her own member state and is valid for five years. This card holds about 28 days worth of data (41). Two other types of cards are also used for installation, maintenance, and operation of the tachograph. A workshop card is used by "fitters" to install, activate, calibrate, and download recording equipment. Enforcement officers use a control card to carry out roadside compliance checks. The tachograph has 3 output

options: printing, which requires a control card, downloading, and in-vehicle display of data (42).

Tachonet. In order to ensure simple, reliable, secure, and efficient information sharing to prevent international violations of driving laws, Tachonet, a European telematic network for sharing of tachograph data is already in development (43). This system will provide a central hub for exchange of information between national administrations responsible for issuing tachographs to ease international enforcement of rest periods and driving times (44). The system includes a secure XMP messaging system, intelligent routers between member states, and central logging statistical information. Each nation will be responsible for national driver files. Accessibility to the network will also be determined by each member state (43).

Toll Collection Interoperability. Currently, the toll collection systems in use in the European Union are not interoperable due to differences in charging concepts, technologies, classification and tariff structure, and legal and institutional backgrounds (36). Anticipating the launch of Europe's own GNSS system, Galileo, the European Commission (EC) has taken bold steps to address this issue. A 2003 EC directive has required that by 2008 all new toll collection systems must be GNSS/GSM based. This year coincides with the planned launch of Galileo. The directive requires that all existing DSRC toll collection systems develop migration strategies by 2010, and fully migrate to GNSS by 2012. The directive seems to be somewhat premature, as Toll Collect, Europe's only GNSS based heavy vehicle toll collection system is not yet fully operational. However, Galileo is predicted to improve upon both the accuracy and reliability of GPS (45). On June 26, 2004, the US and EU signed an agreement to coordinate Galileo and GPS (46). In order to ensure that technologies have developed as predicted and that industry will be prepared for the change, the directive requires a technology review to be completed by December 2007. If the review finds that technology has appropriately advanced, the EC hopes to develop a plan for a fully interoperable European service by 2010 (47).

INFRASTRUCTURE MANAGEMENT

In addition to examining regulations and user fees, the Committee for the Study of Freight Capacity for the Next Century also concluded that infrastructure management is essential to effective freight management (1). An indirect goal of all of the European toll collection

systems was to improve efficient use of vehicles and load capacities; however, the effectiveness of these systems for this purpose is yet to be seen. In Canada, the Saskatchewan Department of Highways and Transportation has entered into a public-private partnership with carriers that attempts to optimize roadway use by allowing carriers to utilize overweight vehicles on specified roadways, providing benefits to both carriers and authorities. Unlike the European systems, this system directly aims to optimize load capacities by allowing the use of overweight and over-dimension vehicles.

Saskatchewan Rural Partnership Haul Program

The Saskatchewan Rural Partnership Haul Program is a public-private partnership between the Saskatchewan Department of Highways and Transportation (SDHT) and commercial carriers (48). The program is designed and operated by IRD. The basic premise of the agreement is to allow carriers to use overweight and over-dimensional trucks to optimize their fleets if they agree to use road friendly vehicle technologies and share cost savings with SDHT. The goals of the program are to reduce hauling costs, provide revenue for highway improvement projects, encourage the use of more road-friendly vehicles, improve highway safety, and provide a mechanism for truck management on the roadway system. The agreement includes details that define vehicle configurations, weights, and dimensions, load specifications, operating and maintenance procedures, driver qualifications, operating cost profiles and financial obligations of each partner, and highway improvement projects. Carriers are required to share the costs savings achieved by using oversized vehicles with highway authorities. The carrier pays incremental costs for bridge and pavement use plus half the net difference in trucking costs to SDHT's Transportation Partnership Fund. The fee is calculated by comparing the gross vehicle weight to the regulation weight and measuring the cost savings achieved.

The agreement is regulated by an Automated Vehicle Monitoring System (AVMS) which includes four sub-systems: an onboard vehicle data collection/storage system, a communication network, a central administration system (CAS), and a remote user query system. The on-board data storage system includes GPS, central tire inflation (CTI), and air-spring suspension weight sensors. The air-spring suspension system allows the central administration system to determine the approximate weight of the vehicle by measuring the pressure in the airbag. CTI is used to monitor the air pressures of all tires to ensure appropriate deflation on secondary roadways. The

communications network currently consists of a cellular network connected by a high speed internet data line. Transmissions are made during off-peak hours to reduce costs, although more frequent transmissions are available if a carrier chooses to pay. The communications network is continuing to evolve, as new technologies such as WiFi that would be useful but may not be available remain under consideration. The CAS collects and stores 90 days worth of data, and summarizes data to be made available to carriers and authorities for user defined queries. The CAS also integrates GPS coordinates with global information systems (GIS) to determine truck routing and usage. The remote query system provided carriers and authorities easy access to vehicle routing, non-compliance, and audit reports.

VEHICLE INSPECTION

Remote systems for vehicle inspection are also in varying stages of research and development. One promising technology that has already been tested and found to be an effective means of identifying brake malfunctions is infrared screening. In the future, this technology could likely be further employed to monitor additional vehicle characteristics.

Infrared Brake Screening

In 1999 and 2000, the Federal Motor Carrier Safety Administration (FMCSA) sponsored testing in four states to examine the effectiveness of infrared brake screening (49). The Infrared Inspection System (IRISystem) tested utilized a camera mounted on the roof of a minivan equipped with a display screen. The operator used the infrared camera to scan the wheels of passing vehicles and identify their temperature. In addition to identifying malfunctioning brakes by their temperature, the system also effectively identified other vehicle problems such as flat or under-inflated tires.

The study found that infrared screening is an effective and valuable technology when applied to vehicles traveling up to 40 mph. Level 1 Inspections confirmed 69 to 76 percent of the problems identified by the system. Fifty-nine percent of the vehicles identified were taken out-of-service for brake violations – a huge increase over the 27 percent removed using traditional screening. However, operators concluded that the current technology is likely not useful for mainline screening, as it would be difficult to identify target vehicles and to examine all wheels traveling at highway speeds.

FUTURE APPLICATIONS

In the future, many additional driver and vehicle inspection technologies will likely be included on board. In addition to the air-pressure sensors used to monitor weights in Saskatchewan, several on-board weighing technologies are in use commercially. Available technologies include load cells, air-pressure sensors, hydraulic pressure sensors, and deflection transducers (50). Although these technologies are widely used by carriers for fleet management, they are not yet commonly used for vehicle enforcement. Several types of on-board driver and vehicle monitoring systems that could eliminate the need for any stopping for inspection are also in development (51). Biometrics and steering-wheel play monitors may eventually be used to remotely monitor drivers. As both communications and weighing technologies continue to evolve, these systems may replace external WIM systems, eliminating the need for any type of weighing infrastructure.

CHAPTER 6. POTENTIAL BENEFITS OF APPLYING TOLLING AND MONITORING SYSTEMS FOR COMMERCIAL VEHICLE ENFORCEMENT

DATA IMPROVEMENTS

Several tolling and monitoring technologies currently in use around the world have the potential to improve the safety and efficiency of commercial vehicle operations if applied in the United States. However, implementing these technologies would likely require the passage of revolutionary legislation redefining truck freight operations in the US. While Europe has already defined GNSS monitoring systems as the future of road user charging, it is unlikely that similar legislation would pass in the US, where carriers are fiercely protective of their privacy. While GNSS may provide extremely accurate travel data with little or no infrastructure required, it also gives the government the ability to constantly monitor vehicle movements. Similarly, digital tachography could be used to collect extremely accurate data for planning as well as greatly improve monitoring of driver hours and speeds. However, while EU law requires the use of digital tachographs in Europe, it is again unlikely that digital tachographs would be as easily implemented in the US.

FINANCIAL IMPROVEMENTS

Implementation of DSRC or GNSS technologies to more accurately calculate road user costs and eventually introduce a user based fee such as a distance based tax could improve the efficiency of the system by charging carriers for their exact roadway use. However, US carriers operating under the current permitting system would likely not desire to pay a user fee, whether it supplements or replaces the current permitting system. Any user fee based charging system will have to provide clear benefits to carriers in order to gain acceptance. The Saskatchewan partnership provides a good example of the benefit of cost-based fees for both carriers and authorities. This system exemplifies the improvements in efficiency that can be achieved by cooperation between carriers and government.

The use of a GNSS/GSM system similar to that planned for the European network has the potential not only to improve road charging efficiency, but it could also nearly eliminate the need for construction or maintenance of any infrastructure for monitoring. While current GSM

transmission costs may be high, it is likely that as communication networks continue to develop, costs will decrease. Introduction of on-board weighing and driver and vehicle monitoring systems could further reduce the need for weighing and inspection infrastructure. However, despite improvements in safety and efficiency, privacy concerns in the US would likely bring opposition to US implementation of GNSS based systems.

ENVIRONMENTAL BENEFITS

Introduction of emissions criteria to determine user fees, whether within the current permitting system or using a distance based heavy vehicle fee using GPS, DSRC, or other technologies, could reduce emissions and improve fuel economy. Both the German and Swiss toll collection systems use emissions criteria for determining the rate of the distance based tax. In addition, trucks are charged whether empty or loaded. By introducing these fees, Swiss and German authorities encourage carriers to reduce their number of trips, utilize full load capacities, and use lower emissions vehicles.

CHAPTER 7. CONCLUSION

WIM, AVI, remote and on-board monitoring, and communications technologies clearly have the potential to improve American truck freight operations if institutional barriers can be overcome. The introduction of any or all of these systems could potentially improve the financial and environmental efficiency of the freight network as well as increase its capacity. In the short term, the introduction of OCR and AVI technologies in addition to the installation of more mainline WIM systems could increase rates of vehicle inspection, reduce congestion and negative environmental impacts due to idling and speed changes, improve safety by eliminating potential conflicts due to weaving and speed changes, and improve data collection for characterization of freight traffic in the network. These systems could be at least partially successfully employed without major administrative changes. In the long term, US states, including Texas, should consider the introduction of various on-board and remote monitoring systems, including GNSS and digital tachography for more efficient road user charging and better driver vehicle monitoring. In addition to improvements in network efficiency, these systems could eliminate the need for nearly all monitoring and inspection infrastructure. However, successful implementation of these systems would likely require major legislative changes, and also necessitate a new level of trust and cooperation between carriers and authorities.

However, Texas should not consider these institutional barriers to be impossible to overcome, but rather should look to the examples provided by the European Union and the Saskatchewan Rural Partnership Haul Program. Although some EU legislation may seem somewhat presumptuous, the European government is looking beyond current technological and administrative differences in an attempt to achieve future interoperability. It will be important for Texas, as well as the United States and its NAFTA trade partners, to overcome existing administrative differences to achieve a truly efficient network. Although its policies are nowhere near as far reaching as the EU's continental legislation, the Saskatchewan Rural Partnership Haul Program provides a successful demonstration of cooperation between carriers and road authorities. By implementing a system that was mutually beneficial, the SDHT was able to achieve a new level of trust with carriers while realizing economic benefits for both parties. The state of Texas should follow these examples by recognizing the importance of establishing trust

with carriers while also looking beyond current technological and institutional barriers in deciding which technologies to implement for the future safety and efficiency of its truck freight network.

FUTURE WORK

The next step in determining the true feasibility of introducing these new technologies in the US is to examine the institutional and privacy concerns that will likely provide barriers to implementation. A study should be performed that examines both government and carrier concerns that have slowed the implementation of ITS technologies in the past. The study should also examine whether similar barriers existed in other nations where these technologies are already in use, or whether the barriers are unique in American society. If similar barriers did exist elsewhere, the study should identify how these barriers were overcome. A variety of solutions to overcoming these barriers should be examined, including traditional legislative changes as well as innovative solutions such as public-private partnerships.

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