RC 1622

March 30, 2015

Evaluating Michigan Commercial Vehicle Enforcement Strategies and Facilities

FINAL REPORT

Valerian Kwigizile, Jun-Seok Oh, Fathi Alkhatni, Randy Jorge
Western Michigan University

Andrew Ceifetz, Joyce Yassin
Opus International Consultants, Inc.

Transportation Research Center for Livable Communities
Western Michigan University

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. MDOT Project Manager
RC 1622	N/A	Jason Firman

4. Title and Subtitle
Evaluating Michigan Commercial Vehicle Enforcement Strategies and Facilities

5. Report Date
March 30, 2015

6. Performing Organization Code
N/A

7. Author(s)
Valerian Kwigizile, Jun-Seok Oh, Fathi Alkhatni, Randy Jorge, Andrew Ceifetz, Joyce Yassin

8. Performing Org. Report No.
N/A

9. Performing Organization Name and Address
Western Michigan University
1903 West Michigan Avenue
Kalamazoo, MI 49008

10. Work Unit No. (TRAIS)
N/A

11. Contract No.
2013-0069

11(a). Authorization No.
Z1

12. Sponsoring Agency Name and Address
Michigan Department of Transportation
Research Administration
8885 Ricks Rd.
P.O. Box 30049
Lansing MI 48909

13. Type of Report & Period Covered
Final Report
05/07/2013 - 3/30/2015

14. Sponsoring Agency Code
N/A

15. Supplementary Notes

16. Abstract
This report documents evaluation results and recommendations for Michigan commercial vehicle enforcement strategies and facilities. Through literature review, online survey and site visits, enforcement strategies and facilities in other states and countries were studied. Site visits of existing Michigan commercial vehicle enforcement sites and review of current and past reports by the Michigan Department of Transportation (MDOT) and the Michigan State Police (MSP) revealed the existing conditions of facilities and potential needs for improvements. Benefit-cost analyses for the existing fixed weigh stations and other enforcement sites were conducted. The results indicated that addition of low-speed Weigh-In-Motion (WIM) with bypass lane is most likely to improve efficiency of a number of existing fixed weigh stations. Also, adding a preclearance system was found to improve efficiency of specific fixed weigh stations. The results, however, showed that fixed weigh stations are not economically beneficial when located along low volume roads. Recommendations for removing such stations are also provided. Furthermore, the report recommends implementation of systems that integrate enforcement technologies and consolidate data to assist enforcement officers in screening and verifying compliance of commercial vehicles.

17. Key Words
Commercial vehicle enforcement, strategies, facilities, technologies

18. Distribution Statement
No restrictions. This document is available to the public through the Michigan Department of Transportation.

19. Security Classification - report	20. Security Classification - page	21. No. of Pages	22. Price
Unclassified	Unclassified		N/A

Disclaimer

Acknowledgements

The research team would like to thank Mr. Jason Firman, the project manager, and Mr. Andre Clover, the research manager, for their unwavering support to this project. We want to give special thanks to Ms. Peggy Johnson of MDOT for coordinating the project. Also, we would like to thank the following members of the Research Advisory Panel for their suggestions and comments, which helped in shaping and carrying out this study:

Brenda Dietrich, Michigan State Police (MSP)

Thomas Kenny, Michigan State Police (MSP)

Lina Chapman, MDOT Intermodal Policy

Will Thompson, MDOT University Region

Vincent Bevins, MDOT Superior Region

Patrick Morris, Michigan State Police (MSP)

Larry Karnes, MDOT Intermodal Policy

Finally, we would like to thank Mr. Scott Flemming, the coordinator of the Indiana State Police (ISP) Commercial Vehicle Enforcement Division (CVED) for his support and coordination of our visit to Lowell fixed weigh station in Indiana.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

A. Research Overview and Objectives

Over the past several decades, there has been significant growth in commercial vehicle traffic in Michigan. Nearly 70% of all of Michigan's freight is shipped by truck and Michigan is ranked eighth in the USA in terms of the value of its exports with $50 billion per year (MDOT 2006). The growth of truck traffic in Michigan is driven by many factors related to economic activities and the need for freight shipping. Growth in truck traffic increases the need to improve commercial vehicle enforcement strategies to ensure compliance to state weight, size and safety laws. Similar to other states, the Michigan State Police (MSP) mainly utilizes fixed weigh stations to enforce Michigan commercial vehicle laws. Currently, Michigan maintains 15 fixed weigh stations used as primary locations for enforcing commercial vehicle regulations. The stations are also used for administrative and training purposes. However, when fixed weigh stations are in operation, commercial vehicle operators are quickly aware and may use alternate routes to bypass them. Other strategies utilized by MSP include mobile screening and check-lane operations. The Michigan Department of Transportation (MDOT) provides and maintains facilities utilized by MSP to enforce commercial vehicle laws. With the annual $1 million capital budget for upgrading and maintaining existing enforcement sites and for building new enforcement sites, MDOT and MSP needed to determine the effectiveness of existing fixed weigh stations and the use of alternative technologies and potential enhancements of the fixed weigh stations. MDOT's investment to protect its road is extremely important in maximizing the life span of the road.

The primary goal of this study was to determine the benefits of each of the existing fixed weigh stations in Michigan, the cost of upgrading, enhancing and maintaining these weigh stations, and the cost of using alternative solutions in place of fixed weigh stations or as an enhancement to it. Benefit-cost analyses were performed to help MDOT and MSP in decision making on future commercial vehicle enforcement strategies.

Specifically, the research had the following objectives:

1. Quantifying the value of each fixed weigh station and selected virtual weigh stations (WWIM and safe enforcement site with a PITWS).
2. Performing a life cycle analysis of each fixed weigh station versus converting it to a virtual weigh station.
3. Evaluating the use of alternative technologies to replace and/or enhance existing fixed weigh stations.
4. Evaluating the safety impacts of each enforcement strategy and assessing the risk in the event a weigh station is closed.

To accomplish the goals of this study, a comprehensive literature review was performed to identify the current practices in the US and other countries. Furthermore, an online survey was administered to all US state's commercial vehicle enforcement agencies and selected provinces in Canada. The survey was aimed at understanding any recent and planned improvements in commercial vehicle enforcement by other states and Canada. Existing MDOT and MSP reports were reviewed to understand the current Michigan commercial vehicle enforcement strategies. Site visits of selected fixed weigh stations and other enforcement sites were performed to gain first-hand understanding of Michigan's commercial vehicle enforcement operations. An additional visit to a fixed weigh station in Indiana (Lowell fixed weigh station, located on I-65) was performed to identify any physical and operational differences between Michigan and Indiana fixed weigh stations. Cost data for each fixed weigh station was collected from MDOT and MSP while conservative estimate of benefits of enforcement strategies was performed through analysis of existing Weigh-In-Motion (WIM) data, crash data, and operational characteristics of these strategies. Benefit-cost analyses were finally performed to compare identified alternative strategies, improvements and upgrades.

B. Research Findings

Through literature review, it was determined that fixed weigh stations still serve as the main locations for enforcing commercial vehicle laws in many US states and other countries. However, these fixed weigh stations are enhanced and improved to increase their efficiency. The main improvements and enhancements include the use of WIM (mainline and ramp) and use of preclearance systems. The mainline WIM facilitates the use of preclearance systems while the ramp WIM (low-speed/sorting WIM) facilitates the use of a bypass lane. Using a preclearance system reduces the number of commercial motor vehicles (CMVs) entering the fixed weigh station through mainline screening of weight, size, and credentials at freeway speeds. Compliant CMVs may bypass the fixed weigh station at freeway speed unless they are selected randomly to enter the fixed weigh station. Adding a low speed WIM with a bypass lane is very beneficial at congested fixed weigh stations because it increases capacity and reduces congestion.

The literature review also revealed that states and other countries use WIM sensors to supplement (and in some cases to replace) fixed weigh stations by implementing mobile screening or virtual weigh stations (VWS). Other improvements and enhancements of fixed weigh stations include use of automatic vehicle identification (AVI) systems, use of cameras, use of over-height detectors and other improvements. It was also found that a number of states and one province in Canada have their state-specific preclearance systems. These include Weigh2GoBC (for British Columbia), NCPASS (for North Carolina), and Green Light (for Oregon). These systems reduce the number of trucks required to enter a fixed weigh station, thus allowing enforcement officers to focus on potential violators more effectively. Quantification of the benefits of such state-specific preclearance systems may need to be explored in the future.

Furthermore, the literature suggested that efficiency of commercial vehicle enforcement officers can be significantly improved by utilizing technology integration and data consolidation systems. Integration of technologies and consolidation of data enables electronic identification and verification of commercial vehicle compliance. This assists officers by allowing them to focus their inspection resources on vehicles most likely to present a significant safety risk. With a limited number of officers to staff enforcement locations, such technologies have the potential to increase efficiency of Michigan Commercial Vehicle Enforcement Division (CVED) officers.

A number of previous studies have examined the safety impact of fixed weigh stations. The literature review revealed that the presence of fixed weigh stations may lead to an increase in the number of crashes due to diverging and merging of commercial vehicles and speed differentials resulting from the need for these maneuvers. However, these studies did not address the potential safety benefits associated with safety inspections of trucks. Heavy vehicles with defects (e.g., defective brakes) may likely be more involved in crashes downstream of the facility. Through commercial vehicle enforcement at fixed weigh stations, such defective trucks are removed from the traffic stream, potentially avoiding a crash.

In this study, safety analysis consisted of three major components: crashes involving defective commercial vehicles, crashes that occurred at the fixed weigh station, and those that happened before and after the facility (in its vicinity). Reduction in crashes involving defective commercial vehicles can be considered a potential cost saving as a result of the presence of enforcement upstream.. Analysis of crashes before the facility focused on two incremental distances of 5,280-ft to 3,000-ft and 3,000-ft to 0-ft in advance of the exit gore. The influential segment after the facility was taken as 1,950-ft from the painted nose of the freeway entrance ramp. The analyses of crashes involving defective commercial vehicles used crashes downstream of the fixed weigh stations and comparison segments with similar characteristics. These segments downstream of the fixed weigh stations were relatively longer segments between the fixed weigh station and the nearest major interchange (intersection) downstream of the fixed weigh station. Similar segments without fixed weigh stations were identified and cross-sectional analyses were performed.

Analysis results indicated that the presence of fixed weigh station facility influences crashes in the 5,280-ft to 3,000-ft segment before the facility only. It was determined that the fixed weigh station could be associated with up to 76 percent of crashes in this section. For the segment at the facility, analysis results indicated that the presence of fixed weigh station can be associated with a reduction of 26 percent of crashes in this segment when compared to comparison sites. However, it was determined that the presence of fixed weigh station does not significantly impact crashes in the 1950-ft segment after the station. Furthermore, analysis of crashes involving defective commercial vehicles indicated that the presence of commercial vehicle enforcement site is more likely to reduce crashes involving defective commercial vehicles downstream of the station by 66 percent. To determine the net safety impact of fixed weigh stations, the influential segment "before facility", the segment "at the facility" and the segment downstream of the fixed weigh stations were considered. The actual number of crashes in all these segments resulting from their respective impacts were computed for all fixed weigh stations and the annual average of these crashes was obtained. Summing up the crashes associated with each impact showed that the overall average net crashes per year is negligible.

A web-based survey was administered to all US states and selected provinces in Canada through their respective commercial vehicle enforcement agencies. A total of 21 US states and 5 Canadian provinces participated in the survey. The survey results revealed that:

- The majority of US states (95 percent) and Canadian provinces use fixed weigh stations for commercial vehicle enforcement.
- About one-third of states and provinces participating in the survey use mainline and low-speed WIMs to improve efficiency of commercial vehicle enforcement operations.
- Safety concerns as well as changes in traffic volume have led states and provinces to remove fixed weigh stations.
- The majority of states (85.7 percent) and provinces (60 percent) do not plan to remove fixed weigh stations in the near future.
- In addition to random and/or scheduled patrol on suspected routes, portable scales and virtual weigh stations (VWS) are used to mitigate the problem of violators bypassing fixed weigh stations.
- Truck volume, state boundary, and highway functional class are the major criteria for locating fixed weigh stations.
- More than half of the participating states and provinces use virtual weigh stations to enforce commercial vehicle laws
- Truck volume, high commercial vehicle violations, availability of utilities for power and communication, access to a safe pullover location, and close proximity to the fixed weigh station are the main criteria in the selection of locations for VWSs.

- The majority of participating US states (57 percent) and Canadian provinces (80 percent) use mobile enforcement strategy.
- Preclearance systems are used in many states (87.7 percent) and Canadian provinces (60 percent).
- About a quarter of US states and 80 percent of Canadian provinces participating in the survey employ check-lane operations as a strategy for enforcing commercial vehicle laws.
- A little over a third (38 percent) of US states participating in the survey use safe enforcement sites with pavement cut-outs/notches to facilitate the use of portable scales while 80 percent of provinces participating in the survey install pavement cut-outs/notches.

Examination of the current Michigan commercial vehicle enforcement strategies revealed that there are significant physical and operational differences among existing fixed weigh stations. It was therefore determined that four levels of fixed weigh stations can be established for planning and analysis purposes: Basic, Intermediate, Advanced and Most Advanced. A basic fixed weigh station has only a static scale, while an intermediate fixed weigh station consists of both a static scale and a mainline WIM. The advanced fixed weigh station consists of a low-speed WIM for sorting traffic as well as a bypass lane, in addition to the features present at an intermediate station. At the highest level, the most advanced fixed weigh station consists of all features of the advanced level, plus a preclearance system. The construction/installation costs by fixed weigh station levels were determined to range from $2.3 million to $3.3 million. The estimated costs required to upgrade each fixed weigh station were determined as shown in Table E-1.

Analysis of citations issued at existing fixed weigh stations indicated that citation fines at all fixed weigh station average about $1.6 million per year. Combining enforcement sites, the statewide citation fines average about $4.5 million per year.

Table E- 1 Costs to upgrade existing fixed weigh stations

Weigh Station	2015 Base Cost	2015 Operating Cost	Annual Labor Cost	Annual Maintenance Cost	Upgrade to Intermediate	Upgrade to Advanced	Upgrade to Most Advanced
New Buffalo_EB	$0	$15,726	$287,789	$41,000	$0	$0	$0
Monroe_NB	$0	$47,584	$287,789	$35,000	$0	$0	$0
New Buffalo_WB	$0	$30,145	$119,912	$41,000	$0	$0	$60,347
Monroe_SB	$0	$29,876	$215,842	$46,000	$0	$0	$60,347
Grass Lake_EB	$0	$26,787	$191,859	$33,000	$0	$0	$60,347
Grass Lake_WB	$0	$19,439	$191,859	$33,000	$0	$0	$60,347
Coldwater_NB	$0	$7,006	$57,558	$36,000	$0	$0	$60,347
Ionia_WB	$1,170,905	$22,635	$143,894	$15,000	$0	$686,676	$747,023
Ionia_EB	$1,170,905	$22,635	$143,894	$15,000	$0	$686,676	$747,023
Fowlerville_EB	$1,856,905	$28,337	$143,894	$15,000	$0	$686,676	$747,023
Fowlerville_WB	$1,856,905	$28,337	$143,894	$15,000	$0	$686,676	$747,023
Powers	$0	$8,337	$47,965	$6,000	$0	NA	NA
Pontiac_SB	$0	$9,088	$59,956	$15,000	$136,000	822,676	$883,023
Telegraph	$500,489	$10,615	$11,991	$15,000	$0	NA	NA
Cambridge	$0	$8,337	$47,965	$8,000	$0	NA	NA

Analysis of factors associated with benefits and costs of enforcement strategies indicated that pavement saving and travel time delays are the main factors affecting the economic value of a given enforcement strategy. It was determined that the most beneficial strategies result from capturing high amounts of overweight trucks without causing unnecessary delay to compliant commercial vehicles. A traffic simulation approach was adopted for estimating the number of overweight trucks caught and the amount of travel delay increased by each enforcement strategy. While travel delays as dis-benefit were monetized by applying truck drivers' value of time (VOT), the pavement cost saving was quantified based on the number of overweight trucks caught. Cost components considered include construction/installation/upgrade costs, operating costs, labor costs, and maintenance costs. Table E-2 summarizes the result of the benefit-cost analyses for existing conditions and for upgrading to advanced level (highlighted blue) or most advanced level (highlighted green). A negative benefit-cost ratio (BCR) signifies that the disbenefits outweigh the benefits. It shows that the station generates more delays enough to outweigh the benefits.

Table E- 2 Benefit-cost analysis results for upgrading fixed weigh stations

Fixed Weigh Station	Highway	Current Level	Current BCR	Advanced BCR	Most Advanced BCR
New Buffalo_EB	I-94 EB	Most Advanced	12.77	N/A	12.77
Monroe_NB	I-75 NB	Most Advanced	8.86	N/A	8.86
New Buffalo_WB	I-94 WB	Advanced	10.09	10.09	10.22
Monroe_SB	I-75 SB	Advanced	8.91	8.91	9.61
Grass Lake_EB	I-94 EB	Advanced	4.00	4.00	4.24
Grass Lake_WB	I-94 WB	Advanced	4.11	4.11	4.24
Coldwater_NB	I-69 NB	Advanced	1.94	1.94	1.73
Ionia_WB	I-96 WB	Intermediate	-0.84	2.01	1.99
Ionia_EB	I-96 EB	Intermediate	-0.84	2.01	1.99
Fowlerville_EB	I-96 EB	Intermediate	-0.30	1.46	1.49
Fowlerville_WB	I-96 WB	Intermediate	-0.30	1.46	1.49
Powers	US-41 & US-2	Basic	1.48	N/A	N/A
Pontiac_SB	I-75 SB	Basic	-0.31	1.14	0.41
Telegraph	US-24 NB & SB	Basic	0.00	N/A	N/A
Cambridge	M-50 & US-12	Basic	0.33	N/A	N/A

Note: Operation hours for each weigh station are assumed to be the same as the current scheduled hours.

Analysis of the 15 existing fixed weigh stations indicated that:

- The two most advanced fixed weigh stations (Monroe NB and New Buffalo EB) are economically beneficial (with BCR values of 8.86 and 12.77, respectively). This can be attributed to their ability to focus on potential violators while allowing compliant trucks to bypass the fixed weigh station, either through mainline (if subscribed to PrePass, or through a bypass lane if detected to comply with regulations).
- All advanced level fixed weigh stations (New Buffalo WB, Monroe SB, Grass Lake EB, Grass Lake WB, and Coldwater) are economically beneficial with BCR values greater than 1.00. However, it should be noted that Monroe SB and New Buffalo WB catch violators who are almost leaving the state of Michigan.

- Intermediate fixed weigh stations at Fowlerville and Ionia may be generating greater disbenefits due to their inability to handle the present truck volume with their current configuration which requires all trucks to enter the fixed weigh station. Further analysis on whether revising the number of hours the stations are open can improve their benefits revealed that they would still be uneconomical regardless of changes in the schedule.
- All basic fixed weigh stations (except Powers) were found to be uneconomical with BCR values of less than 1.00. Powers, the only fixed weigh station in the Upper Peninsula, is one of the most isolated fixed weigh stations such that an overweight truck caught at this station would have potentially travelled a long stretch of highway before being caught, hence damaging more pavement. Similar to the intermediate level, further analysis on whether revising the operation schedule can improve their benefits revealed that they will still be uneconomical regardless of changes in the schedule.

Upgrading the current intermediate fixed weigh stations (Ionia and Fowlerville) and one basic fixed weigh station (Pontiac) to advanced level (i.e., adding a bypass lane) was analyzed. Upgrading these five fixed weigh stations to the advanced level would significantly improve their performance and make them economically beneficial (with BCR values greater than 1.00).

Analysis results for upgrading fixed weigh stations by adding preclearance systems showed that:

- While Monroe SB, New Buffalo WB, Grass Lake EB, and Grass Lake WB fixed weigh stations would have slightly improved economic benefits, Coldwater would become less beneficial (BCR value changing from 1.94 to 1.73). The decline of benefits at Coldwater can be explained by the fact that adding the preclearance system will add installation and maintenance costs while not significantly changing the number of violators caught.
- While installing preclearance systems (together with adding bypass lanes) at the Fowlerville EB and Fowlerville WB fixed weigh stations may improve their current economic benefits, the improvement would not be significantly different from when only a bypass lane is added.

- Comparing the benefits gained by improving Ionia EB and Ionia WB to the most advanced (adding a preclearance) to just advanced (adding a bypass lane only) showed that adding a preclearance system would reduce its economic benefits.
- For the Pontiac fixed weigh station, adding a preclearance system (together with a bypass lane) will result into reduced economic benefits compared to when just a bypass lane is added.
- An alternative to adding both a bypass lane and a preclearance system to the existing basic and intermediate fixed weigh stations is to add a preclearance system only. This can allow a significant number of compliant trucks to bypass the fixed weigh station (if precleared) and therefore minimize the delay and congestion caused by the requirement for each truck (including compliant trucks) to enter the scale facility. Economic analysis indicated that this approach could be even more beneficial. However, this approach requires a more detailed assessment of what proportion of truckers are willing to subscribe to the preclearance program, especially for fixed weigh stations utilized predominantly by intrastate tucks. Economic analysis in this study assumed the average proportion observed currently at Monroe NB and New Buffalo EB fixed weigh stations.

Analysis of the mobile enforcement strategy indicated that the approach plays a very important role in increasing the visibility of law enforcement officers and therefore deter potential violation of commercial vehicle laws. They also deter potential use of routes bypassing a given fixed weigh station. However, these benefits are not quantifiable and as such, have not been included in the benefit-cost analysis. Using the quantifiable costs and benefits, the results indicated that mobile enforcement cannot replace fixed weigh stations. Mobile enforcement using wireless WIMs should be used to supplement fixed weigh stations by focusing on potential bypass routes, especially where criteria for locating a fixed weigh station are not met.

C. Recommendations

This study recommends the following:

- A number of fixed weigh stations be enhanced/upgraded to improve their economic value. Specifically, the study recommends that Ionia (eastbound and westbound), Fowlerville (eastbound and westbound), and Pontiac (southbound) fixed weigh stations be considered for upgrading to the advanced level (i.e., add low-speed WIM and bypass lane). Consideration to improve stations to the most advanced (i.e., adding preclearance system without adding low-speed WIM and bypass lane) can be made after an additional study to determine the potential proportion of truckers willing to subscribe to the service is conducted.
- With the exception of Powers which is an isolated fixed weigh station, the removal of fixed weigh stations from routes with CADT less than 2,200 should be considered. Specifically, Cambridge and Telegraph fixed weigh stations should be considered for removal.
- Based on existing potential violation rates shown by WIM sensors and based on truck volume, adding one fixed weigh station in the southwest part of Grand region should be considered. The specific location will depend on availability of the right of way. However, I-196, I-96 or US-31 may be potential candidate locations. Further study is needed to confirm this need, based on analysis of origin-destination and travel paths of trucks in the region.
- Consider implementation of systems that integrate enforcement technologies and consolidate data to enable electronic identification and verification of safety compliance of commercial vehicles. This has the potential to improve efficiency by ensuring that officers focus their inspection resources on those vehicles, carriers and drivers most likely to present a significant safety risk. Fixed and mobile systems should be considered for implementation.
- Mobile screening should continue to be used as a supplemental strategy focusing on potential bypass routes with higher potential violation rates. This strategy, supplemented with mobile systems of integrated technologies and data consolidation, have the potential

to provide the necessary deterrence on routes unsuitable for a fixed weigh station (e.g., those locations with higher violation rates, but CADT less than 2,200).

- Periodically review commercial vehicle traffic and routes to see where mobile weight enforcement should be applied. The decision to maintain a given enforcement site should be based on potential violation rate and coverage.
- Continue check-lane operations focusing on safety-related issues of commercial vehicles.
- Conduct further research on integration of technologies and consolidation of data to enhance commercial vehicle enforcement. Additional research is also needed to confirm the need to add a new fixed weigh station in Grand region. It is also important to study the impact of the location of the sign informing truckers of the presence of a fixed weigh station one mile downstream. The current one mile distance may not be optimal. Finally, it is also beneficial to evaluate the possibility of Michigan to develop a statewide preclearance system such as GreenLight (used in Oregon) or Weigh2GoBC (used in British Columbia) or expanding the nationwide systems such as PrePass and DriveWyze. Such systems have the potential to increase the number of precleared commercial vehicles and relieve congestion at fixed enforcement locations.

1 INTRODUCTION

1.1 Research Motivation and Background

Over the past several decades, there has been significant growth in commercial vehicle traffic in Michigan. Nearly 70% of all of Michigan's freight is shipped by truck and Michigan is ranked eighth in the USA in terms of the value of its exports with $50 billion per year. The growth in Michigan's commercial vehicle traffic is driven by several factors such as:

- The North America Free Trade Agreement (NAFTA) which removed obstacles to trade with Canada and Mexico. This resulted in a significant increase in the volume of goods shipped across the US/Canada border by truck. It has also increased Michigan exports headed to Mexico.
- As the home of the North American Auto Industry, Michigan is a major manufacturing hub in which a significant proportion of the industry's freight is moved by truck. The industry's freight traffic is expected to continue to grow.
- Commercial shipping has emerged as an essential link in the just-in-time market delivery models used to reduce warehousing and storage costs. Michigan businesses such as the auto industry, Whirlpool, Dow, and many others rely on the just-in-time delivery model, and thus have a significant interest and stake in the state's commercial vehicle infrastructure.
- The diversification of Michigan's economy. Whereas 20 years ago the economy in Michigan was primarily manufacturing-based, today it is diversified to include more resource-based, warehousing, retail, and value-added services requiring the import and export of goods.

The above trends are expected to be sustained. At the same time, additional factors are expected to further boost the economic performance of the state and increase the movement of goods by truck. These include:

- The construction of the New International Trade Crossing (NITC) bridge to Canada, which is expected to increase the movement of truck traffic around Detroit, specifically along I-75, I-94, and I-96. This new crossing will offer significant shipping time savings.
- Several new intermodal freight terminals are planned or being constructed, with the largest being in Detroit. Flint and Toledo, Ohio, also are planning or implementing strategies to increase intermodal freight. The expected result in Michigan will be growth and consolidation of these areas as warehousing and transit points which will increase truck freight activity to and from Michigan.
- Local agencies in Wayne and Washtenaw counties are working to develop the Detroit Regional Aerotropolis which will leverage the excess capacity at Detroit Metro and Willow Run Airports. Once fully implemented, this will significantly increase the volume of commercial vehicles on Michigan's roadways.
- The recent growth in the oil and gas industry in Michigan and other Midwestern states is resulting in the development of significant generators and attractors of truck traffic.
- Mexico is Michigan's second largest trading partner. Growth in the Mexican economy is expected to continue, and the value of Mexico's trade with Michigan is expected to continue growing at a rapid pace. This will further increase the volume of truck traffic on Michigan's roadways.

There have been many efforts in the United States to improve commercial vehicle enforcement strategies by adopting new technologies. These technologies either replace or enhance fixed weigh stations. California Department of Transportation (Caltrans) in collaboration with Partners for Advanced Transit and Highways (PATH) conducted a comprehensive study to evaluate cost-effectiveness of enforcement strategies (Santero et al, 2005). The study found that across the top ten Weigh-In-Motion (WIM) sites with the most potential benefit in California, the average pavement life saved was 10.71 percent. Also, the study found that using Virtual Weigh Stations (VWS) as an enforcement tool is advantageous because they can be located in crowded urban areas where traditional weigh stations may be too costly and space-consuming to install.

The Connecticut Department of Transportation (ConnDOT) conducted a study in which, among other objectives, they identified technologies and practices that have the potential to increase the efficiency and effectiveness of weigh and inspection stations to deter the passage of overweight and unsafe vehicles across the state's highways (Pines and Fang, 2008). Among other suggestions, the study recommended that ConnDOT install and use WIM and e-screening technologies for the state's network of permanent and portable weigh and inspection stations in order to achieve increased efficiency and effectiveness of the state's enforcement activities while at the same time serving to encourage commercial vehicle compliance with state requirements and regulations. More examples of studies on commercial vehicle enforcement strategies include a study by the Maryland State Highway Administration, Motor Carrier Division, which in particular investigated approaches for selecting commercial vehicles for inspection (Hahn and Pansare, 2009). The study demonstrated that the virtual weigh station (VWS) approach improved the effectiveness of commercial vehicles selection methods significantly over a traditional method relying on random manual selection. In addition, due to the benefits of the VWS, a study conducted for the Minnesota Department of Transportation recommended that all existing WIM sites be upgraded to Virtual Weigh Stations (URS, 2007). However, none of the studies recommended elimination of fixed weigh stations mainly because of their potential benefits over other strategies, especially when located correctly (e.g., at state boundaries) and equipped with necessary technologies to enhance their performance.

The above examples signify the needs for investigating current Michigan practices on weigh stations as well as alternative technologies to improve the commercial vehicle enforcement strategies based on lessons from other states and Canada. The outcomes of this work include recommendations to the Michigan Department of Transportation (MDOT) and the Michigan State Police (MSP) on the best enforcement strategies and enhancements to the existing weigh stations to increase efficiency and effectiveness of the state's enforcement activities. Implementation of new strategies and/or enhancements of the existing enforcement sites are expected to improve MDOT and MSP efficiency on commercial vehicle enforcement as well as save pavement lives by minimizing the percentage of overweight trucks on Michigan's roadways without adding much additional cost to the trucking industry.

1.2 Research Problem Statement

The growth in freight movements by truck through and within Michigan has resulted in the need for more efficient and sustainable commercial vehicle enforcement in order to maintain safety and minimize pavement damage caused by overweight trucks. Currently, Michigan maintains 15 fixed weigh stations used as primary locations for enforcing commercial vehicle regulations. The stations are also used for administrative and training purposes. However, when fixed weigh stations are in operation, operators become quickly aware and may use alternative routes to bypass them. As a result, Michigan has implemented supplemental enforcement strategies such as permanent intermittent truck weigh stations (PITWS). Coupled with Wireless Weigh-In-Motion (WWIM), the PITWS facilitate mobile enforcement to supplement the existing fixed weigh stations. To improve efficiency, fixed weigh stations can be enhanced with technologies such as preclearance systems and low-speed WIM installed in the ramp to sort trucks and allow the compliant trucks to use the bypass lane. With the annual $1 million capital budget for upgrading and maintaining existing enforcement sites and for building new enforcement sites, MDOT and MSP needed to determine the effectiveness of existing fixed weigh stations and the use of alternative technologies and potential enhancements of the fixed weigh stations. Benefit-cost analysis of each of the 15 fixed weigh stations in Michigan and benefit-cost analysis of alternative solutions needed to be performed to help MDOT and MSP in decision making regarding future commercial vehicle enforcement strategies and enhancements. Since the fixed weigh stations are the only legal places to weigh a vehicle if the operator objects to using a PITWS site, it was imperative that the value of each of these stations be determined and benefit-cost analysis be conducted. Detailed information on the advantages and disadvantages of each enforcement strategy and enhancement was also required. Other factors that needed to be considered were the significance of the corridor, border weigh stations, commercial volume, percent overweight, safety and redundancy.

1.3 Research Objectives

The main goal of this study was to quantify the benefits of each of the 15 fixed weigh stations in Michigan; the cost of upgrading and maintaining these weigh stations; and the cost of using alternative solutions such as WWIM, safe enforcement sites, or PITWS. Specifically, the research had the following objectives:

1. Quantifying the value of each fixed weigh station and selected virtual weigh stations (WWIM and safe enforcement site with a PITWS).
2. Performing a life cycle analysis of each fixed weigh station versus converting it to a virtual weigh station.
3. Evaluating the use of alternative technologies to replace and/or enhance existing fixed weigh stations.
4. Evaluating the safety impacts of each enforcement strategy and assessing the risk in the event a weigh station is closed.

The recommendations presented in this research are intended to serve as the necessary foundation to guide investment decisions in the infrastructure and facilities needed to efficiently and effectively provide commercial vehicle enforcement.

1.4 Scope of Work and Report Format

This study focused on the existing commercial vehicle enforcement strategies. Potential enhancements and improvements of fixed weigh stations using technologies identified through literature review and survey of other states and Canada were also evaluated.

The second chapter of this report documents findings from the literature review on commercial vehicle enforcement strategies and technologies in the United States and other countries. Chapter 3 documents the findings from the survey of US states and selected provinces in Canada to identify current commercial vehicle enforcement practices and future plans to enhance enforcement. Chapter 4 focuses on the details of commercial vehicle enforcement strategies in Michigan. Conditions of existing fixed weigh stations are documented in this chapter as well as the need for improvements. This chapter also documents observations made by the research team during site visits as well as performance of existing enforcement sites. Chapter 5 documents analysis of factors associated with costs and benefits of enforcement strategies and provides a summary of how they were analyzed in this study. Chapter 6 documents the benefit-cost analyses and provides a summary of key findings with details given in the appendices. Finally, Chapter 7 summarizes the conclusions and recommendations of this study.

2 LITERATURE REVIEW

2.1 Introduction and Overview of Commercial Vehicle Enforcement

Commercial motor vehicles (CMV) support the state and nation's economy through movement of freight. However, CMVs violating state weight and safety regulations may damage the infrastructure prematurely and pose other dangers to the traveling public. Many studies [for example Han *et al* (2012), Hanson *et al* (2010), and Chan (2006)] have shown that overweight trucks reduce the pavement lifespan of a roadway since the pavement is specifically designed to accommodate or serve a given stress in a number of load repetitions. Higher axle loads and heavier loads have less allowable repetitions for using the pavement and if the allowable load repetitions are exceeded, the pavement life may be reduced significantly. This may also increase the maintenance costs of a roadway network. Overweight trucks not only contribute to pavement deterioration, but also reduce the service life of bridges and other roadway structures.

Weight enforcement strategies have been shown to be an effective way of limiting or minimizing the number of weight limit violations and thus minimizing their effects on pavements and road networks. In another study (Santero, Nokes, & Harvey, 2005), it was found that the average pavement life saved using weight enforcement strategies can be as high as 10.71 percent. Weight enforcement is typically done at specific points on a highway network where installation of commercial vehicle enforcement facilities has been justified. The enforcement also includes checking vehicle size (width, length, height, truck-trailer combinations, etc.). When enforcement is done well, it helps protect public investment on road networks and improve safety of all road users.

Fixed weigh stations were the only effective enforcement and deterrent tool in the past. Because the road network for trucks was limited, fixed weigh stations were not easy to bypass. Prior to the popularity of citizen band (CB) radios and cellular phones, truck operators had no prior knowledge of the operational status of the stations, even if the location was known. Today, the trucking industry's communication network is so advanced that shortly after opening a fixed weigh station, approaching truck operators hear the word. Bypassing a fixed weigh scale or failing to stop is considered a violation in many states. The Michigan vehicle code 257.724 states that: "*A driver* *or owner of a commercial vehicle with other vehicles or trailers in combination, a truck or truck tractor, a truck or truck tractor with other vehicles in combination, or any special mobile equipment who fails to stop at or bypasses any scales or weighing station is guilty of a misdemeanor*" (Michigan, 2014). To mitigate the bypassing problem, alternative strategies and technologies such as the installation and use of Weigh-In-Motion (WIM) sensors on potential bypass routes have been adopted. These technologies allow for supplemental enforcement strategies such as mobile screening and virtual weigh stations (VWS).

2.2 Commercial Vehicle Enforcement Strategies

Due to the several shortcomings of fixed weigh stations (e.g., easy to bypass, high cost to operate and maintain, and increasing CMVs travel time and delays), the need and implementation of alternative technologies and enhancement strategies to improve commercial vehicle enforcement has increased recently (Han *et al* (2012), Hanson *et al* (2010), and Chan (2006)). There have been notable efforts in the United States to improve commercial vehicle enforcement strategies by adopting new technologies. These technologies and strategies either supplement or enhance fixed weigh stations. Similar efforts have been observed in other countries (see USDOT, 2009; Lee et al, 2013; Ismail et al, 2010; Evans and Klashinsky, 2012; and McBride and Kirby, 2012). A detailed discussion of alternative enforcement strategies and technologies is provided below.

2.2.1 Fixed Weigh Stations

These are the traditional weight enforcement stations. A basic fixed weigh station consists of a scale house that is staffed with enforcement officials and a static scale used to weigh commercial vehicles. However, additional features and technologies can be added to increase efficiency of the weigh station. These include preclearance system, WIM sensors, over height detectors (OHD) and other technologies. The main functions of a fixed weigh station are to enforce weight limits, provide safe inspection points where thorough inspection can be done, safe location to park out-of-service (OOS) trucks and to provide a safe location for offloading vehicles or shifting loads to attain legal weights. Without additional technologies, all commercial vehicles are required to enter a fixed weigh station, although some commercial vehicles bypass the fixed weigh station unlawfully. Overweight trucks may also travel when weigh stations are closed, at night, and on weekends. Because weigh stations are often bypassed or otherwise avoided by overweight trucks, supplemental or alternative strategies are warranted (FHWA, 2009).

Technical requirements for fixed weigh stations

A static scale is required to weigh the trucks and transmit data to the control panel located inside the scale house. A setup of the control panel utilized at a fixed weigh station with a static scale is shown in Figure 2.1.

Figure 2.1 Observation desk at a fixed weigh station

Advantages of fixed weigh stations

It is beneficial to have a designated location where a scale house is located because it acts as a visible deterrent to potential overweight trucks. The fewer overweight vehicles are on the road the lesser the impact on pavement conditions, extending the life span of the road's infrastructure. This is considered as a cost savings to MDOT and would also result in fewer maintenance activities to sustain adequate pavement conditions. The fixed weigh station is a traditional method of commercial vehicle enforcement, therefore MDOT is well experienced with this implementation and the type of required operations.

The MSP and commercial vehicle drivers also benefit from having a fixed weigh station. The fixed weigh station is a safe location to conduct enforcement operations, and also consists of a parking area where commercial vehicle owners are able to park out-of-service vehicles, or shift loads/offload to attain legal weights. Also, by providing locations for inspecting trucks, fixed weigh stations increase the likelihood of removing defective trucks from the traffic stream. This may be advantageous to all stakeholders as crashes involving defective commercial vehicles can be minimized.

Disadvantages of fixed weigh stations

As noted above, the disadvantages of fixed weigh stations include the potential high costs associated with construction, maintenance, and operations. Costs associated with crash risks resulting from exit and entry points where trucks are accelerating and decelerating, may also be higher.

The fixed facilities do not allow MSP to roam the network identifying unsafe or overweight vehicles, therefore limiting them to one static location. In addition, the effectiveness of fixed weigh stations may be limited due to being unable to identify violators bypassing the station. Their effectiveness, however, can be improved by implementing supplemental enforcement strategies such as mobile enforcement to deter the bypassing problem.

2.2.2 Safe Enforcement Check Lane Operations

Safe enforcement check lanes are currently conducted in Michigan and other states. In Michigan, all trucks are directed to exit the mainline and enter the check lane temporarily setup at a rest area or vacant lot. Visual inspections are conducted focusing on the safety condition of the commercial vehicle. If a vehicle is visually suspected of being overweight, a PITWS is available to weigh the vehicle. However, the main focus of check lane operations is safety inspections and not weight. The research team had an opportunity to attend one of these operations which was conducted at the Zeeland rest area located on east bound I-196 in Ottawa County.

To improve the operations of a safety enforcement check lane and include weight enforcement, WIM sensors can be utilized to weigh every truck upon entering the check lane. Two types of WIMs can be used when performing a safety enforcement check lane operation; a portable WIM or a permanently installed high-speed WIM located in advance of the Safety Enforcement sites. However, this has the potential to create longer queues which may lead to other unintended problems.

In the state of New York, fixed weigh stations are non-existent. The preferred practice is utilizing high-speed WIM devices located in advance of rest areas. Suspected overweight vehicles are then directed to exit the mainline by variable message signs. Once the suspected overweight vehicle exits, the vehicle is reweighed to confirm the WIM reading. The use of variable message signs reduces commercial vehicle traffic entering the rest area. The disadvantage of having compliant vehicles bypass the rest area is fewer trucks are inspected for other safety compliance.

Advantages of check lane operations

The advantage of safety check lane operation is to allow officers to check for safety of all commercial vehicles, which ensures that all trucks are safe to be on the road with the general traveling public. Advancing these operations, would also allow officers to focus on weight restrictions. This can also be viewed as a benefit for MDOT and commercial vehicle owners to ensure that the operating vehicles are safe, and to ensure overweight vehicles are not causing increased pavement deterioration.

Disadvantages of check lane operation

The disadvantage to commercial vehicle owners is that all drivers will experience significant delay during this type of operation. In some instances, drivers will try to bypass the check lane or park on the shoulder, and additional officers may be needed to detect such potential violators.

Possible organizational issues

If not already in place, a formal agreement between the rest area owners (MDOT) or property owners of the check lane location and the MSP department may be beneficial to ensure smooth operations.

2.2.3 Virtual Weigh Stations (VWS)

A Virtual Weigh Station (VWS) is a system made of a Remote Monitoring System (RMS) and a WIM system combined together. The VWS are essentially intended to provide an alternative low-cost system that can be installed on any roadway and would deliver the functionality of a fixed weigh station. They are more likely to be installed in locations where a fixed weigh station would not be feasible economically or environmentally, an example being in urban areas (Cambridge Systematics, Inc., 2009).

The screening process can be manual or automatic. In the manual screening process, officers are able to monitor the VWS, and receive data wirelessly. A commercial vehicle that is noncompliant is then chased and intercepted by the officer. In cases where an officer is unavailable to intercept the noncompliant vehicle, the screening process can be automated. Based on a series of criteria, such as weight, past compliance with size and weight standards, the screening software can be programmed to identify non-compliant commercial vehicles. In these cases, issuing warning letters or citations may be considered. Issuing warning letters to commercial vehicles that are noncompliant on a regular basis is consistent with the Federal Motor Carrier Safety Administration (FMCSA) new operational model (Comprehensive Safety Analysis for 2010) (Cambridge Systematics, Inc., 2009).

Technical requirements for VWS

To improve functionality, advanced roadside based technologies, such as optical character recognition of the license plate and DOT numbers may be implemented to automatically identify violators. Other requirements include: Commercial Vehicle Information Exchange Window (CVIEW), state-issued permit compliance, repository of past weight performance, driver identification system, augmented WIM scales, and two-way communication systems.

Advantages of VWS

The advantage associated with employing VWS is that it can be used to monitor commercial vehicles continuously. The enforcement agency can use the data collected to monitor overweight vehicles, and identify time frames where mobile enforcement should be deployed. VWS also has the capabilities to detect tailgating, speeding and driver maneuvers intended to cheat the system.

Disadvantages of VWS

The disadvantages of VWS include the lack of opportunity to perform safety inspections similar to those performed at fixed weigh stations. VWS are also discreet and do not provide a visible deterrence to reduce the occurrence of overweight commercial vehicles. They also may require additional resources to issue citations to non-compliant drivers.

Institutional and organizational issues associated with VWS

Due to the potential inaccuracies of high speed WIMs and state law prohibiting automated enforcement, VWS cannot be fully functional in some states, including Michigan. Similar actions taken during the mobile weight enforcement operations are needed for officers to verify the weight of the vehicle at a nearby static scale. Image capturing has also presented difficulties, especially in capturing quality images of USDOT numbers due to lack of retro-reflectivity and standardization. Poor images produce complications in automating data processing.

2.2.4 Mobile Weight Enforcement

Mobile screening is a strategy in which high-speed WIM collects real-time data which officers can access wirelessly with an in-vehicle laptop computer. To employ Mobile Weight Enforcement, an officer parks downstream of the WIM location, generally in the median or an inconspicuous location. The officer monitors the information received wirelessly from the WIM. Once a suspected overweight vehicle is flagged, the officer utilizes the vehicle type information provided by the WIM to track and intercept the vehicle. In some cases, the flagged vehicle may not be easily identified by the officer due to heavy commercial vehicle traffic and the lack of a unique identifier.

Operational details and approach

To advance mobile screening operation, technologies to assist in vehicle identification (such as capturing image of the suspected overweight vehicle) can be implemented. This technology would improve operations by clearly identifying the vehicle which officers can then more accurately track and intercept. Another advancement that is currently being utilized in Michigan in combination with Mobile Weight Enforcement is the use of Permanent Intermittent Truck Weigh Scales (PITWS). The PITWS consist of a cut-out or depression in the pavement for convenient use of portable scales. The utilization of PITWS reduces delay by at least two-thirds compared to the time required to weigh a commercial vehicle with a traditional portable scale, which requires placing boards on both sides of the axle to level the tire with the portable scale. PITWS are currently installed at 48 different locations, where 19 of the locations are at rest areas. The installation of PITWS can be more widely implemented, particularly downstream of high-speed WIM locations where Advanced Mobile Weight Enforcement can be operated. PITWS can be installed at rest areas, safe enforcement sites, state and county garages, and carpool parking lots. They can also be installed on shoulders where Average Annual Daily Traffic (AADT) is low and there is adequate clearance between the cut-out and the mainline.

Technical requirements

The high-speed WIM system consists of a scale installed on the mainline which weighs the vehicle, a roadside processing unit that estimates the vehicle's weight, and a wireless communication system that transmits captured data to the laptop located in the enforcement vehicle. Loop detectors may also be installed to capture additional parameters such as axle configuration and speed. High speed WIMs should be calibrated on a regular basis to maintain accuracy. In addition to these technical requirements, a camera can be installed to capture images of the vehicle which can be utilized by the officers to easily identify overweight vehicles.

Advantages of mobile weight enforcement

Compliant commercial vehicle drivers do not encounter any delay by having to enter and exit a fixed location. Mobile weight enforcement operations allow officers to rove the network by not limiting them to a static location as is the case with a fixed weigh station. This is also a benefit as officers are more visible to road users. Stopping a violator on the roadside creates awareness of enforcement activities.

Disadvantages of mobile weight enforcement

The disadvantages of utilizing high speed WIMs as an enforcement tool include accuracy and institutional limitations. For example in Michigan, a commercial vehicle identified as being overweight by a high speed WIM needs to be reweighed by a portable scale due to the varying accuracies. This can be a time consuming process for the officer, particularly in situations where a PITWS is not available. As a result, officers may capture very few violators because of the amount of time it takes to process one violator. Image capturing has also presented difficulties in capturing quality images, particularly in night time and adverse weather conditions.

Possible organizational issues

The safety of enforcement officers when utilizing PITWS has been raised as a concern. It is important that adequate clearance from the travel way is provided at all times to assure the safety of officers during mobile enforcement operations.

2.3 Commercial Vehicle Enforcement Technologies and Enhancements

Alternative enhancements and technologies can improve commercial vehicle enforcement at fixed weigh stations. These technologies and enhancement features include the installation of a preclearance system, addition of bypass lane with low-speed WIM for vehicle sorting, and variable message signs for communication and speed displays. Other enhancements and technologies include over-height detectors (OHD), thermal imaging system for brake and safety inspection, vehicle identification technologies such as cameras, automated license plate readers (LPR), USDOT number readers, and automatic vehicle identification (AVI). The addition of a bypass lane with low-speed WIM facilitates enforcement and improves efficiency by allowing compliant vehicles to bypass the fixed weigh station. The following sections describe these technologies and enhancements in detail.

2.3.1 Weigh in-Motion

Weigh In-Motion (WIM) is a system for measuring weight in which sensors are installed beneath the pavement to measure the axle loads of moving vehicles. At a WIM sensor, overloading is detected depending on a predefined threshold weight (FHWA 2009 & Han, et al 2012) which is set as a percentage of the legal weight. Once the software has detected a weight violation, data about the violator is collected and processed using the roadside computer and can be transmitted if communication systems are present. With proper technologies, the violators can then be directed to the static station for a more accurate check and possible citation via a message sent and displayed on a variable message sign (Jacob & Beaumelle, 2010; Zhang et al, 2008).

A typical WIM system will generally consist of a scale installed on the mainline or ramp to record the weight of the vehicle, a roadside processing unit that estimates the vehicle’s gross weight as well as axle weight and other captured details, and a communication system that can be wireless or cabled, which transmits the captured data to an enforcement unit. Common WIM sensor technology types include bending plate, piezoelectric (quartz, ceramic and polymer), and load cell. Details of these technologies can be found in McCall & Vodrazka Jr., (1997); Katz, (2001); and Ali et al., (1994).

A study by FHWA (FHWA, 2009) reported significant factors affecting precision of the WIM sensor to include: WIM technology used, installation and calibrations, pavement conditions, testing truck, speed, temperature changes and pavement smoothness. The WIM site needs to remain free of surface distresses such as rutting which would influence the manner in which vehicles pass over the WIM and thus result in less reliable data. The study recommended that the smoothness of the pavement where WIM are installed must be checked annually using a high speed profiler (FHWA, 2009).

High-Speed or Mainline WIM

High-Speed WIM systems are commonly used to screen vehicles on the mainline stream for weight compliance as they approach a fixed weigh station. The WIM scale or sensor embedded in the pavement automatically weighs vehicles and estimates the vehicle's weight – an estimate which can be used for sorting purposes. Typically, sorting/screening is based on estimates from WIM sensors or scales on the mainline that are compared to a weight pass/fail threshold set to a percent of the legal weight. Thresholds are adjustable by station personnel. Trucks that exceed the threshold are directed into the weigh station to be weighed on more accurate static scales where citations can be issued. This technique is very simple and safe to operate because it only requires detectors to be installed beneath the pavement of the mainline and a small roadside control and communication box adjacent to the mainline (see Figure 2.2). Additional roadside technologies can be added depending on the needs.

Figure 2.2 Mainline WIM detector and wireless control box

High-speed WIM systems can be used to conduct mobile enforcement. In this regard, when a commercial motor vehicle (CMV) passes over a WIM sensor, information such as speed, number and spacing and weight of each axle can be stored in a database and sent from the WIM wireless control box to the nearest fixed weigh station or patrol vehicle. If that CMV violated the weight/size limits, a patrol officer can pull it to the nearest enforcement site (e.g. weigh station or PITWS) for more accurate measurement. Figure 2.3 shows a CMV being verified using the nearest PITWS after it was detected by high-speed WIM during site a visit conducted by the research team.

Figure 2.3 Weighing a CMV using pavement cut-outs

Mainline weight screening using high-speed WIM has a number of benefits such as significantly increasing the capacity of fixed weigh stations. In the absence of mainline WIM sensor, all commercial vehicles are required to enter the fixed weigh station. This may lead to regular formation of queues which may force the closure of weigh stations. As a result, violators may pass the fixed weigh station without being checked. If the station is not closed, the queue may extend to the mainline and therefore cause safety hazards to the traveling public.

Low-Speed or Sorting WIM

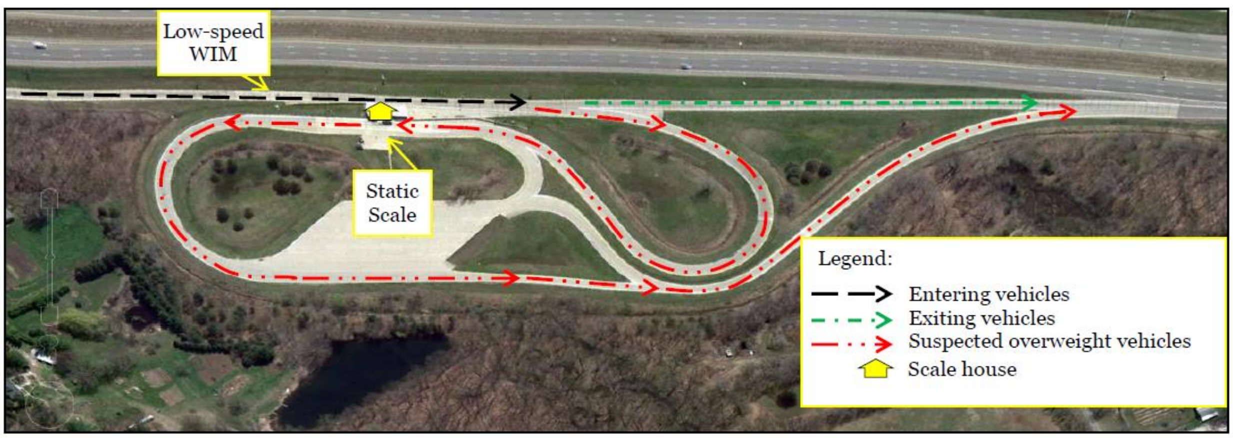
A low-speed WIM is installed on the ramp to a weigh station, in combination with a bypass lane. The low-speed WIM is used to sort commercial vehicles based on the weight thresholds. In addition to weight, the axle spacing, vehicle height, and vehicle classification may be determined. Vehicles that exceed the set threshold are signaled to enter the static scale to be weighed. Compliant vehicles continue in the bypass lane to exit the weigh station and return onto the mainline with minimum delay.

2.3.2 Bypass Lane

This feature involves physical changes in the fixed weigh station configuration by adding a bypass lane supported with low-speed WIM which sorts vehicles. The low-speed WIM is installed in the entrance of the exit ramp to sort and signal CMVs either to use the bypass lane to re-enter the mainline or enter the static scale for further weight or size inspections (Kamyab, 1998). The objective of installing a by-pass lane is to increase the operating capacity and reduce incidents of congestion on the exit ramp and mainline (i.e., backup on the roadway). In their study, Benekohal et al, (1999) point out that up to 50.8 % (about 30% on average) commercial vehicles bypassed the weigh stations due to a queueing problem.

The static scale can either be located in front of the scale house adjacent to the bypass lane, or in the back of the scale house. Figure 2.4 illustrates two different layout configurations of a fixed weigh station which includes a bypass lane. The top layout configuration shown in the figure is the most desirable. In this design the static scale is located in front of the scale house, adjacent to the bypass lane. Vehicles suspected to be overweight are weighed on the static scale located adjacent to the bypass lane. Therefore, the distance traveled is close to the distance traveled on the bypass lane. As a result, this design saves travel time that would have otherwise been added for a vehicle to go through a static scale located behind the building.

Static scale adjacent to bypass lane



Static scale not adjacent to bypass lane

Figure 2.4 Bypass lane with low-speed WIM configuration

The design shown in the bottom layout configuration is less desirable. In this design the static scale is located in the back of the scale house, requiring suspected overweight vehicles to travel a longer distance at low speed. To accommodate the distance traveled, a larger land area may be required. This design also requires drivers and station attendants to cross the static scale truck lane when accessing the parking lot area. This poses a safety hazard to both truck drivers and scale attendants. With the scale behind the building, a single attendant would need to divert their attention from the freeway and bypass lane when weighing a vehicle.

Adding a low speed WIM with a bypass lane is very beneficial at congested fixed weigh stations because it increases capacity and reduces congestion. This is a cost saving strategy both to state and commercial vehicle owners because it reduces delay while enabling law enforcement officers to be more efficient by focusing on potential violators. However, since sorting is based solely on weight, vehicles with safety issues but legal weight will be allowed to bypass. Installing e-screening technologies may alleviate this deficiency.

2.3.3 Preclearance Systems

Preclearance systems are a sophisticated enforcement technique that integrates weigh-in-motion sensors with transponders installed in CMVs and corresponding readers installed in the mainline traffic stream. The majority of preclearance systems, including PrePass, consist of a Radio-Frequency Identification (RFID) transponder in each vehicle that is registered in the program. A high-speed WIM weighs each of the passing commercial vehicles to determine if they meet weight and other regulations. The transponder is also linked to the fixed weigh station to verify that all credentials are in compliance with state regulations. A message is then sent to registered transponders directing the driver whether or not to bypass the fixed weigh station.

The system reduces the number of CMVs entering the scale through mainline screening of weight, size, and credentials at freeway speeds. Compliant CMVs may bypass the fixed weigh station at freeway speed unless they are selected randomly to enter the fixed weigh station. If a CMV is detected to be noncompliant, it is directed through onboard message display systems to enter the fixed weigh station for additional weight/size and safety inspections (Lee et al., 2013). The safety benefit of this technique include minimizing CMVs maneuvers in the proximity of weigh station such as acceleration, deceleration, and changing lanes, and therefore reducing the potential conflicts in the vicinity of fixed weigh stations.

While the nationwide/regional preclearance systems such as PrePass, NORPASS and DriveWyze PreClear are popular, a number of states and provinces have developed their own state-specific preclearance systems. These include GreenLight, NCPass, and Weigh2GoBC. The following sub-sections summarize these state-specific preclearance systems.

Green Light

Through its $20 million federal grant (plus a 20% match) to modernize its weigh stations and show the benefits of using weigh-in-motion scales and transponders, Oregon developed the project 'Green Light' (ODOT 2013). Green Light provides mainline screening for commercial vehicles by enabling preclearance through integration of WIM, automatic vehicle classifiers (AVC), over-height detectors, axle sensors and loops, automatic vehicle identification systems, variable message signs (VMS) vision technology and supervisory system computer (SSC). The system allows vehicles to be weighed, classified, identified and checked for height violations. Green Light checks weight, height, safety and other registration and tax related issues as a truck crosses the WIM scales. The information is then processed against online real-time databases by the SSC for verification and to check if other important credentials are within requirements. Then a bypass or pull in for further detailed inspection information is relayed back to the driver depending on the results of the checks. The prioritization of installation sites was based on locations with higher traffic volumes.

NCPASS

NCPass^{TM} is a weigh station pre-clearance program in the state of North Carolina (NCPass, 2013). This program is voluntary and allows participants the opportunity to bypass fixed weigh stations across the state of North Carolina. The program has been fully functional and operating successfully since October 2007. It is reported to also support transponders from NORPASS or BESTPASS pre-clearance systems. Trucking companies can enroll in the program for an annual enrollment fee varying from $40 to $70 per truck. The annual fee is based on whether the company already has compatible transponders, the number of trucks the company is enrolling and length of time the company elects to be part of the program.

The range of bypass rates are 35-90% depending on a carrier's past performance at roadside inspections (Safestat scores) and good weight compliance history. Using formulas developed by North Carolina State Highway Patrol (NCSHP), which are subject to review regularly, a favorable bypass rate is granted to qualifying operators with satisfactory rating issued by FMCSA.

Weigh2GoBC

British Columbia, through its Weigh2GoBC, which is a network of WIM and Automatic Vehicle Identification (AVI) technologies, enables more efficient commercial vehicle movement through its network of static fixed scales at weigh stations (B.C. Ministry of Transportation and Infrastructure, 2013). Through the system, once a commercial vehicle is weighed at a Weigh2GOBC enabled station, it is given a bypass through the rest of the stations within 12 hours. Each time it passes an AVI enabled station a verification is performed to determine whether it has been checked at such a site within 12 hours. If not, it is signaled to report to an inspection station. However, regardless of the results of electronic screening, a Random Report Percentage (RRP) can lead a truck to be signaled to report to the station. This is similar to PrePass in which one out of five trucks may be signaled to report to the station.

2.3.4 Thermal Imaging Inspection System

Some of the violations such as those related to brakes being out of adjustment, air compressor violations, defective drums, inadequate brake linings, inadequate tubing and hoses, connections with leaks and defective parking brake systems, can be easily detected by the use of infrared thermal imaging (Green, 2009). In a project that tested infrared camera application for the testing of heavy truck braking safety and risk (Salonen, 2012), it was reported that the infrared camera technology is best suited for detection of wheels with very low temperatures that signify brakes not working or working inefficiently, and detection of high temperatures over 300°C which may signal problems with the braking system.

It was also reported (Salonen, 2012) that temperature differences of about 50% of the brakes on the same axle may signal a problematic braking system and hence can be used to decide on further inspection of the braking system.

2.3.5 Cameras and Optical Character Recognition (OCR) Systems

Cameras are beneficial to determine when back-ups are extending onto the freeway mainline. In some instances, the cameras can be used to see if commercial vehicles are utilizing the shoulder to park. It has been reported that video image sensing techniques are able to produce individual vehicle information. The system uses overhead cameras that automatically take a picture of every passing vehicle and process the image to extract useful information including vehicle length, width, and color, (See Figure 2.5). The extracted information from both upstream and downstream detection stations can be correlated, and then re- identify vehicles (Amelia Regan et al., 2006).

Figure 2.5 Camera at Pontiac fixed weigh station (I-75 SB)

2.3.6 Variable Message Signs (VMS)

Two types of variable message signs are currently being used in Michigan: forward/back/stop signs and speed limit signs. The forward/back/stop signs are found to be useful to instruct truck operators of the necessary movements when the truck is being weighed. The variable speed limit signs are found to be useful particularly when delays occur, and trucks begin to back-up onto the main roadway. If this occurs, the speed limit is generally raised to get the trucks through the weigh station faster, and therefore reduce queuing (See Figure 2.6).

Figure 2.6 Speed limit VMS at Monroe fixed weigh station (I-75 NB)

2.3.7 Over-Height Detector (OHD)

An over-height vehicle detection system detects over height vehicles moving toward overhead obstacles, such as bridges, tunnels and other structures, and individually warns drivers. The system provides the driver with the opportunity to actively avoid a collision with an overhead structure. The system is comprised of a transmitter and a receiver. The transmitter contains either an infrared or high intensity, visible red light source that is pulsed across the highway from the transmitter to the receiver. The receiver is designed to issue an alarm if the red beam is blocked by an object at least 5 cm (2") in diameter, 2.5 cm (1") above the line of detection and moving between 1 km/h (~1 mph) and 120 km/h (75 mph). The transmitter and receiver may be direction discerning, which triggers the alarm only when vehicles traveling in a certain direction are considered over height. The alarm activates a warning sign with alternating flashers and/or an audible alarm. In the event of a failure, the system will not activate the flashers on the sign, but will display a constant message, such as “warning - height restriction”. This system reduces damage to structures by over height vehicles. The driver is made aware of the danger ahead and is provided with the opportunity to take alternate action or an alternate route (International Road Dynamics Inc., 2006). Such overheight detectors can be installed on the ramp to detect overheight vehicles and alert the officers at the static scale.

2.3.8 Automatic Vehicle Identification (AVI)

Components of an Automatic Vehicle Identification (AVI) system include license plate reader (LPR) or USDOT number reader. These are designed with digital image capture and identification capabilities through a digital camera or cameras augmented with specialized optical character recognition (OCR) software to isolate and identify specific characters and numbers making up a license plate number and/or USDOT number. AVI systems relieve the need for visual recognition, whether it is based on direct observation of the vehicle itself or examining a photo of the vehicle. The LPR or USDOT reader can interface with a state’s Commercial Vehicle Information Exchange Window (CVIEW) to retrieve safety and credential information associated with the vehicle identified automatically by its license plate or USDOT number. Additionally, license plates can be searched in the National Crime Information Center (NCIC) or other database, further expanding the screening factors. AVI deployment allows screening on safety, credentials, and criminal justice information as well as weight by associating WIM readings and can considerably reduce the time required to retrieve additional information about a suspected vehicle (Cambridge Systematics, Inc., 2009).

AVI improves identification of violators by obtaining license plate numbers and company linked numbers and therefore eliminate the need for manual keying. However, difficulty to capture images when speeds vary widely and to read improperly displayed numbers limits applicability of such technology. Also timing and lighting adjustments are necessary for this technology. Lack of standardized license plates; poor license plate condition; and the same license plate number in different jurisdictions pose additional challenges. Furthermore, license plate found on back of single unit trucks may not be readable by front-reading LPR.

2.3.9 Integration of Technologies and Consolidation of Data

Enforcement of commercial vehicle laws requires identifying potentially at-risk vehicles and stopping them at designated areas to conduct inspections. Inspections conducted include weight, size, safety and driver credentials. Traditionally, identification of vehicles is done visually and credentialing is achieved through inquiring specific information from multiple databases such as FMCSA Safety and Fitness Electronic Records (SAFER), National Law Enforcement Telecommunication System (NLETS), etc. Integration of technologies and consolidation of data enables electronic identification and verification of safety compliance of commercial vehicles to ensure that officers focus their inspection resources on those vehicles, carriers and drivers most likely to present a significant safety risk. With limited number of officers to staff enforcement locations, such technologies have the potential to increase efficiency of enforcement officers.

There are a number of technologies that can be integrated to facilitate detection of vehicle information necessary to query details about the status of the vehicle and the drivers. The core sensors include overview camera (OVC), License Plate Readers (LPR), and USDOT Number Reader (DOTNR) (IIS 2015; Kissick, J. *et al* 2013; & HELP Inc. 2015). Other sensors can include brake sensors (thermal imaging systems), WIM sensors, static scales, Commercial Vehicle Safety Alliance (CVSA) sticker reader, overheight detectors, HazMat placard reader, and radiation detectors. Information generated by these sensors can be used to query the databases and generate alarms based on rules (e.g., vehicle overweight, plate mismatch, HazMat violation, etc.) through a common platform and single interface consolidating these databases.

Technologies can be installed at fixed locations (such as fixed weigh stations and VWS) or even in mobile vehicles such as van or trailers (HELP Inc. 2015 & IIS 2015). Installation of technologies can be accomplished through vendors (for example SmartRoadside, provided by Intelligent Imaging Systems Inc., 360SmartView, provided by HELP, Inc., etc.) or in-house. The

Kentucky Automated Truck Screening (KATS) program is an example of in-house technology integration and data consolidation to enhance screening of trucks. Technologies can be installed in the mainline or on ramps to allow the information to be transmitted and reviewed by enforcement officer downstream or at the scale building. Also, with VMS vehicles can be guided on whether to enter or bypass the enforcement location. To install technologies at virtual weigh stations (VWS) and fixed weigh locations, a total cost of $250,000 - $400,000 per site should be considered. The total cost per site includes the acquisition and installation of the core sensors (OVC, LPR, and DOTNR) and the software and license as well. An additional $150,000 - $220,000 should be added to the total cost per site to install thermal imaging technology. The total cost for the mobile trailer ranges between $250,000 – $350,000, which includes installation, conditioning and training. Also, the total cost for the mobile van ranges between $300,000 and $600,000 depending on the features added.

2.4 Commercial Vehicle Restrictions in Michigan

2.4.1 Michigan Weight Limits

Michigan, which is an axle-based state (not a gross vehicle weight-based state) for the purpose of enforcing, has a unique and complex law as shown in Table 2.1. The uniqueness of Michigan law is the many possible configurations given a commercial vehicle axle spacing arrangement. Since 1982, federal law has required all states to allow gross vehicle weights of 80,000 pounds on the interstate system and other designated highways, and for certain distances off these highways (MDOT, 2013). Maximum allowable axle loadings are the same for a standard truck in all states, but Michigan allows use of more axles in combination with lower axle loadings, for a greater gross vehicle weight than other states (MDOT, 2013). Before World War II, Michigan did not limit the number of axles that could be used on trucks. Between 1942 and 1967, there were limits on overall length and per-axle loading, limiting vehicles to a maximum of thirteen axles and a gross weight of 169,000 pounds. Since 1967, the maximum number of axles has been limited to eleven, and per-axle load restrictions have resulted in a maximum gross vehicle weight of 164,000 pounds (MDOT, 2013).

The truck-weight law restricts axle loads instead of gross vehicle weight due to a research finding that axle loadings are directly related to pavement damage as compared to gross vehicle weight. Therefore, Michigan limits the weight allowed on individual axles, depending on the spacing between them. There are three main spacing distributions under two major classifications based on gross vehicle weight. The first classification considers vehicles exceeding 80,000 pounds of gross weight, while the second classification considers vehicles with 80,000 pounds or less gross vehicle weight.

Table 2-1 Maximum allowable commercial vehicle weights in Michigan

NORMAL LOADING MAXIMUM GENERAL INFORMATION				
Spacing between Axles	*Normal Loadings When Seasonal Load limitations are not in force (Speed Limit 55 MPH*		*FROST LAW Seasonal Load Limitations (Speed Limit 35 MPH)*	
	Vehicles Exceeding 80,000 lbs. Gross Weight	Vehicles 80,000 lbs. or Less Gross Weight	Rigid	Flexible
9 feet or over	18,000 lbs.	20,000 lbs.	13,500 lbs.	11,700 lbs.
More than 3 1/2 feet but, less than 9 feet *normal loading	13,000 lbs.	13,000 lbs.	9,750 lbs.	8,450 lbs.
When part of a tandem axle assembly *on designated routes only	*16,000 lbs.	34,000 lbs. on tandem	12,000 lbs.	10,400 lbs.
When less than 3 1/2 feet	9,000 lbs.	9,000 lbs.	6,750 lbs.	5,850 lbs.
Maximum load on any wheel shall not exceed: (lbs. per inch of tire width)	700 lbs.	700 lbs.	525 lbs.	450 lbs.
**On any legal combination of vehicles with no more than 5 axles, only one (1) tandem axle assembly shall be permitted at the gross weight of 16,000 lbs. per axle and no other tandem axle assembly in such combination of vehicles shall exceed a gross weight of 13,000 lbs. per axle. On a 5 axle tandem-tandem combination both tandems are allowed 16,000 lbs. per axle.*				

2.4.2 Michigan Seasonal Weight Limits

With the state of Michigan also being affected by extreme weather conditions, the law specifies axle load reductions of 25% and 35% for roads with rigid and flexible pavements respectively. In addition, the speed limit is lowered in order to minimize the impact of trucks on pavement during the spring cycle of freezing and thawing. By law, road agencies can enact weight restrictions on roads that are not designated as all-season routes when conditions merit. Table 2.1 shows the Michigan seasonal weight limits.

2.5 Analysis of Traffic Safety

This section gives an overview of previous research work on the impact of the presence of roadside facilities (i.e., weigh stations, and rest areas) as well as freeway ramps on the frequency and severity of crashes and the statistical methods employed in crash analysis.

2.5.1 Impact of Fixed Weigh Station Facility

Few studies have examined the frequency and/or injury severity of crashes that occurred in the vicinity of weigh station and rest area facilities. Benekohal et al. (1999) conducted a pilot study at a weigh station in Springfield, Illinois, to explore the potential benefits of ITS technologies for commercial vehicle operation (CVO) applications. The study monitored delays and conflicts that occur without an automated bypass system or Vehicle Roadside Communication (VRC) system, including automatic vehicle identification (AVI) and a high-speed weigh-in-motion (WIM) needed for electronic screening of trucks. The Illinois Department of Transportation was interested in evaluating the effectiveness of an automated bypass system for intrastate application called the vehicle roadside communication (VRC) system that would use automatic vehicle identification and a high-speed WIM to facilitate electronic screening for trucks at the weigh station. Their results showed that even during light traffic conditions, general traffic slow down or change lanes due to commercial vehicles entering or exiting from the weigh station. In sections with higher traffic volumes, the potential for traffic conflicts increases significantly. The study showed that a higher rate of flow interruption occur in diverge areas, and thus this area may experience more crashes. To reduce potential conflicts and prevent crashes, the study indicated that diverging areas should be given more attention in terms of signing and marking. The study indicated that using AVI/WIM in CVO can help to reduce traffic interruption and reduce the travel delay experienced by trucks to improve traffic safety and increase productivity. Mitigating potential conflict incidents is more likely to increase safety (decrease crash incidents) and decrease driver stress.

Barnett and Benekohal (1999) examined crashes related to the presence of weigh stations on freeways to predict the reduction in crash frequency by using weigh-in-motion and automatic vehicle identification technologies in the vicinity of weight/inspection enforcement locations. The research was interested in the reduction of crashes around weigh stations that could be achieved by using WIM-AVI. The influential segment around a weigh station was taken to include 2,500 feet before and after the facility. The comparison segment was taken to include a basic segment before a weigh station that has the same geometric and environmental characteristics as the influential segments. The study was conducted on eight weigh stations and compared with eight similar basic freeway segments. The study examined injury severity level, type of vehicle involved in crashes, light and weather conditions, AADT and the percent of commercial vehicle composition of the traffic. The study used two sets of crashes - the first set were crashes that occurred during at all times of day, and the second set of crashes was of those that occurred during the typical working hours of weigh stations. Two analyses were conducted in the study: a comparison analysis was used to identify crash patterns and crash frequency around the weigh station's influential segments, and a nonlinear regression analysis was used to develop a model to estimate crash reduction through the use of WIM and AVI technologies. The comparison showed that there were 38 percent fewer accidents in the comparison segments than in the influence segments.

Gattis et al. (2010) studied the behaviors and characteristics of heavy vehicles as they accelerate to merge into the mainline traffic from fixed weigh stations. These behaviors and characteristics included speed, distance, and time measured at several locations on the ramp, besides the weight and volume of individual vehicles. The objectives of the statistical analyses were to examine the effects of truck weight, freeway traffic volume, roadway grade, and other site characteristics on measures such as tractor trailer truck speed and to develop equations to predict truck speed at a given distance. Analysis of variance (ANOVA) and multivariate analysis of variance (MANOVA) tests were performed. Research studies have indicated that increasing speed differentials between vehicles often leads to maneuvers (e.g., improper lane changing, tailgating, etc.) that may lead to crashes (Solomon 1964, Harkey et al 1990, Garber and Gadiraju 1998, Garber and Ehhart 2000). To reduce the magnitude of these speed differentials, longer acceleration lanes are needed so that the majority of trucks can accelerate and enter the flow of traffic on the freeway at a speed closer to that of the mainline. The findings suggest that it is undesirable to locate weigh stations at places where the re-entry ramps would be on an upgrade of more than approximately +0.1% to +0.2% for 3000ft or more. The findings argue against raising the speed limit on a four-lane freeway where heavy volume of trucks enter the freeway on short entry ramps, which increase the potential for higher differentials in speed. The project did not consider all factors that affect the operation of CMV on freeway entrance ramps, such as a wide range of roadway grades, sight distance limitations, ramp curvature, and ramp entrance control.

While most studies focused on crash occurrence as a result of maneuvers dictated by the presence of fixed weigh stations, none of the studies addressed the potential safety benefits associated with safety inspections of trucks. Heavy vehicles with defects (e.g., defective brakes) may be more likely to be involved in crashes downstream of the facility. Through commercial vehicle enforcement at fixed weigh stations, such defective trucks are removed from the traffic stream, potentially avoiding a crash. In this study, crashes involving defective trucks downstream of the fixed weigh stations were examined.

2.5.2 Impact of Rest Area Facilities

In general, vehicle maneuvers at rest areas and weigh stations are similar. However, at weigh stations, only commercial vehicles are required to enter when the station is in operation. Few studies conducted safety risk analyses of the presence of a rest area along a roadway. Pezoldt et al (2011) and Gates et al (2012) investigated the effect of presence of rest area facilities on comfort, convenience, and safety. They concluded that rest areas facilities serve to improve the freeway safety (by reducing fatigue-related crashes) and promote comfort and convenience of travelling. However, the studies did not focus on all merge/diverge crashes in the vicinity of rest areas.

Banerjee et al. (2009) studied the relationship between fatigue-related crashes and the location of rest areas in California. The study compared the ramps of rest areas to other ramps. They found that there was a low frequency of crashes on rest area ramps and the majority of crashes related to rest area ramps occurred in parking lots. Moreover, they concluded that fatigue and non-fatigue crashes sharply decreased downstream of rest areas.

Similar studies (e.g., SRF Inc., 2007) analyzed the relationship between single vehicle truck crashes and rest area spacing. The results indicated that the frequency of single vehicle truck crashes increased during the night time once the spacing distance between two consecutive rest areas was more than 30 miles.

2.5.3 Factors Contributing to Freeway Ramp Crashes

The ramp of a freeway facility basically functions as the ramp of a freeway interchange. Several previous studies have been conducted to evaluate the safety performance of freeway ramps. There were two concerns looked at in the ramp safety studies: freeway diverging areas and freeway merging areas. The injury severity in crashes that occurred at diverging and merging areas could be influenced by several factors such as roadway design, traffic control, traffic volume, environment, vehicle characteristics, and road user characteristics.

Khorashadi (1998) used ANOVA test to forecast the relationship among ramp configuration, geometric parameters and crash frequencies. They used data from the state of California between 1992 and 1994. The study concluded that the geometric elements have less impacts compared to impact of ramp configurations and 15 percent of crashes occurred on ramps. Furthermore, they found that AADT of freeway (regardless of whether the ramp was located in urban or rural area), the length of acceleration and deceleration lanes, and ramp length, are significant factors.

Janson et al. (1998) examined the relationship of ramp design to commercial vehicle crash frequency. In order to study commercial vehicle crashes that occurred on the freeway, they used geometric variables such as the type of ramp (diamond, loop, directional, outer connector and others), ramp connection type (freeway-to-freeway, freeway-to-arterial), interchange type (diamond, cloverleaf, directional, other), conflict areas (ramp, merging/diverging area, upstream and downstream) and crash type (rollover, rear end, sideswipe, and other). Statistical comparisons were conducted between four different types of ramps in three states (California, Colorado, and Washington). Among other findings, the study concluded that conflict areas of ramps (i.e., merging and diverging areas) are the most hazardous areas. McCartt et al. (2004) studied 1,150 crashes that occurred on heavily traveled freeway ramps in order to gain more understanding of the type and pattern of crashes on urban freeway ramps in north Virginia. They found that almost half of crashes happened when at-fault drivers were exiting the freeway. They also found speed and congestion to be significant factors. Speed was mostly a factor in run-off-the-road crashes and congestion was a primary factor in rear-end crashes.

3 SURVEYING OTHER STATES AND CANADA

3.1 Introduction and Objectives of the Survey

To identify commercial vehicle enforcement strategies implemented in other states and Canada, a web-based survey was conducted. The survey also was aimed towards determining the effectiveness of strategies implemented in other states and Canada. It focused on weight/size enforcement strategies, technologies implemented/planned, as well as evaluation results (if any). In addition to the web-based survey, a physical site visit to Indiana's fixed weigh station was conducted.

3.2 Administration of the Web Survey

A web-based survey was designed and administered to all US states through their respective commercial vehicle enforcement agencies. The agencies responsible for commercial vehicle enforcement were identified and verified through telephone and e-mail communications prior to sending the actual survey. This was important to ensure the survey was sent to appropriate agencies since a number of states do not have designated commercial vehicle enforcement units. Similarly, six provinces in Canada were invited to participate in the survey. These provinces were selected based on their proximity to Michigan. Online responses were finally gathered and analyzed.

3.3 Web-based Survey Results

3.3.1 Introduction

The survey results were mainly focusing on specific commercial vehicle enforcement strategies and technologies. A total of 21 US states and 5 Canadian provinces participated in the survey. These are shown in Figure 3.1. As shown, there was a wide range of responses from agencies in the United States.

Figure 3.1 States and Provinces participating in the survey

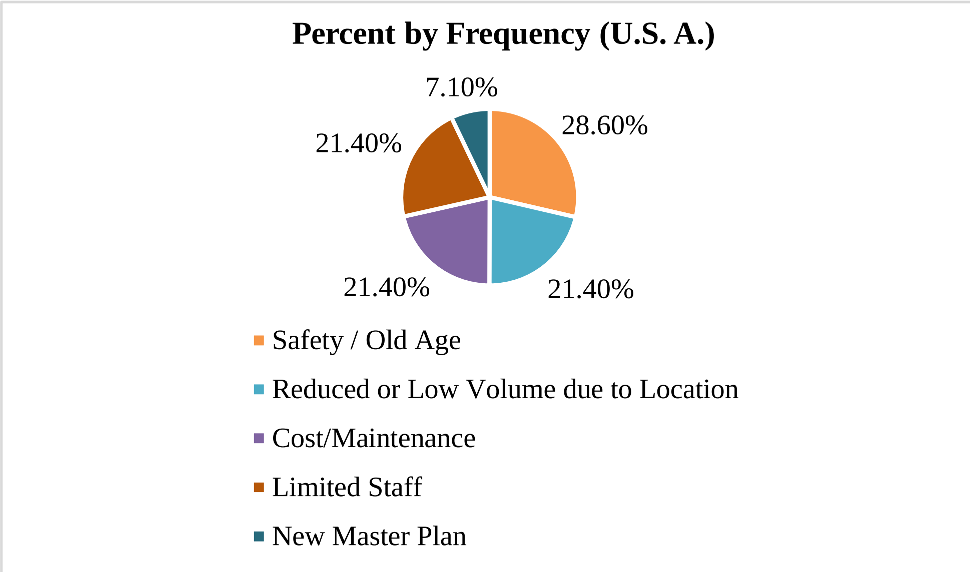
The following are the summary results for each question in the survey. Appendix 3.1 presents more details of the survey questions and results.

3.3.2 Fixed Weigh Stations (FWS)

Questions seeking to understand whether and to what extent fixed weigh stations are being utilized by states and provinces to conduct commercial vehicle enforcement were analyzed. It was determined that more than 95 percent of the participating US states and all Canadian provinces participating in the survey use fixed weigh stations with a static scale for commercial vehicle enforcement.

Mainline WIM sensors and low-speed WIM sensors are important technologies to enhance the efficiency of fixed weigh stations. States participating in the survey indicated that on average only 30 percent of their fixed weigh stations employ mainline WIM sensors while 36 percent employ low-speed WIM sensors. For Canadian provinces surveyed, participants indicated that only 10 percent (9 out of 93) of their fixed weigh stations are equipped with mainline WIMs while about one percent (1 out of 93) of the fixed weigh stations utilize low-speed WIMs. It should be noted here that the sample size for provinces participating was too small to make any definitive conclusions.

To understand any changes states and provinces are making regarding the use of fixed weigh stations, participants were asked if they have recently removed any fixed weigh station facilities. While 52 percent of US states participating in the survey indicated that they have removed fixed weigh stations, 60 percent of Canadian provinces surveyed indicated that they have removed fixed weigh stations. Figure 3.2 presents the distribution of reasons for removing fixed weigh stations stated by participants in both the US and Canada. As it can be seen, safety concerns and/or age of the fixed weigh stations are the main reasons for removing fixed weigh stations in the US. Other reasons include low volume, high maintenance costs, and limited staff. Others indicated that new master plan led to removal of fixed weigh stations.



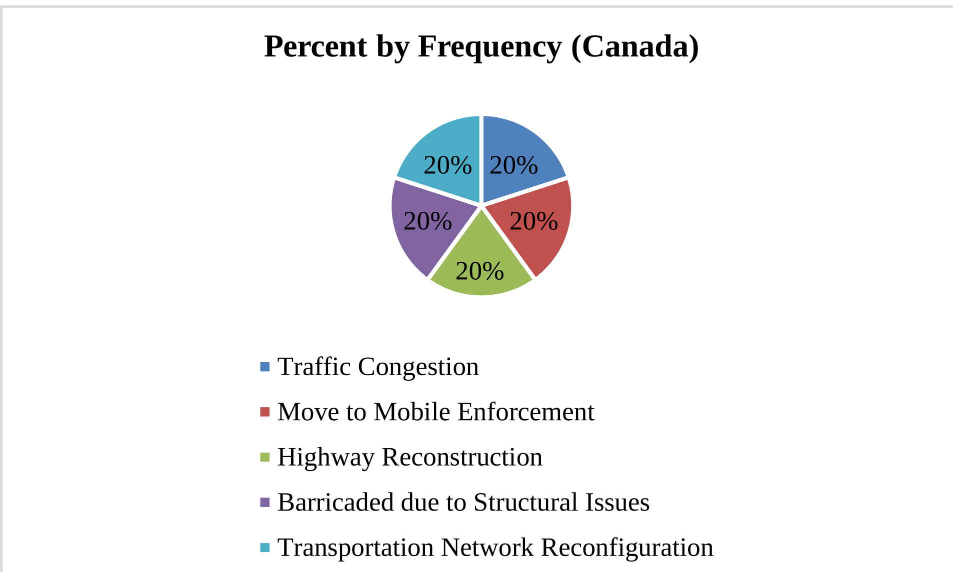


Figure 3.2 Reasons for removing fixed weigh stations in the US and Canada

When asked if they plan to remove more fixed weigh stations in the future, about 86 percent of participating US states stated that they are not planning to remove fixed weigh stations in the near future. Similarly, respondents from three provinces stated that they have no plans to remove fixed weigh station, while one indicated that they have plans to relocate one fixed weigh station. The respondents from the remaining province did not know of any future plans.

When asked about their plans to add more fixed weigh stations, nearly 29 percent of responding US states and 20 percent of responding Canadian provinces stated that they have plans to add new fixed weigh stations in the near future (Figure 3.3). Those planning to add more fixed weigh stations in the near future cited location and the need to replace/renovate fixed weigh stations as reasons for the plans to add new fixed weigh stations.

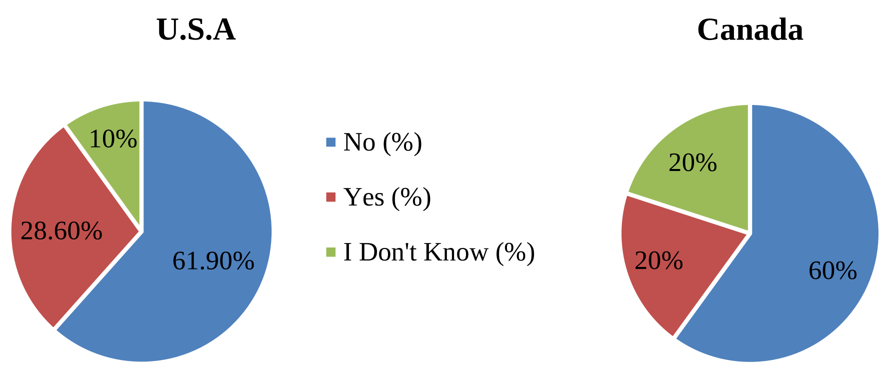


Figure 3.3 States and provinces planning to add fixed weigh stations in the near future

Regarding strategies to deal with the problem of violators bypassing fixed weigh stations, responding states and provinces indicated that the main strategy was to conduct random and/or scheduled patrol on suspected bypass routes, as shown in Figure 3.4. Furthermore, about 43 percent of responding US states indicated that they use portable WIM (PWIM) scales, while 38 percent of responding states indicated that they use virtual weigh stations (VWS) to deal with the bypassing problem.

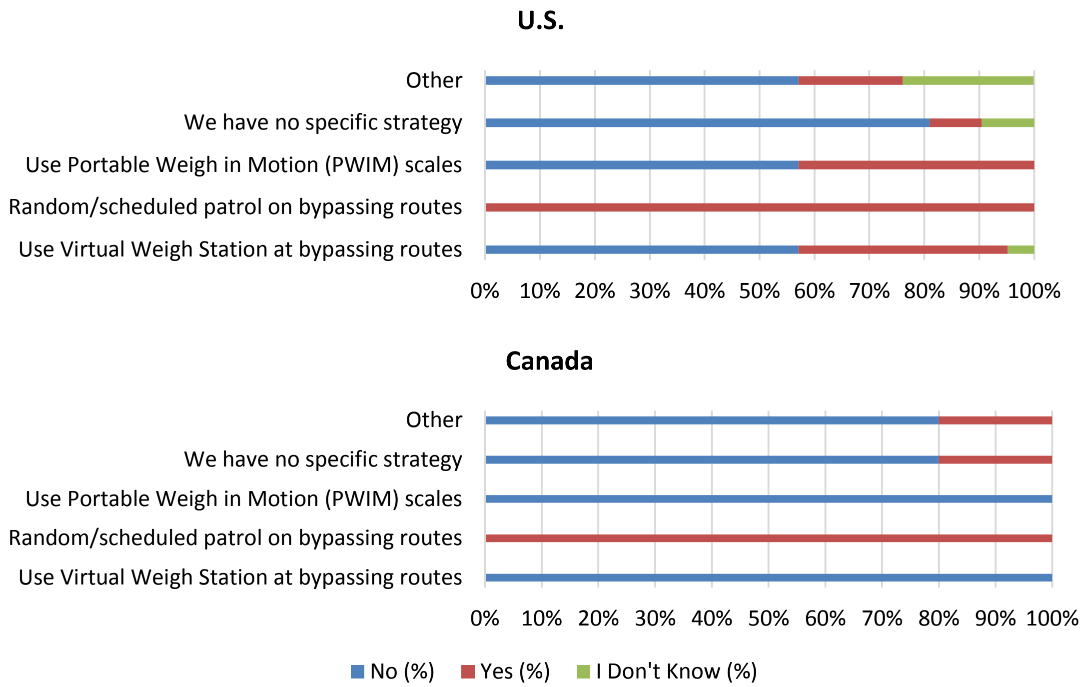


Figure 3.4 Percent distribution of strategies to deal with bypassing problem

To understand the criteria for locating fixed weigh stations, respondents were asked to rate a number of factors on how they influence their selection. As shown in Figure 3.5, more than 80 percent of US states indicated that truck volume influence their decision to locate their fixed weigh stations highly, followed by whether the location is on state boundary. For Canadian provinces, truck volume was shown as the main factor influencing location of their fixed weigh stations.

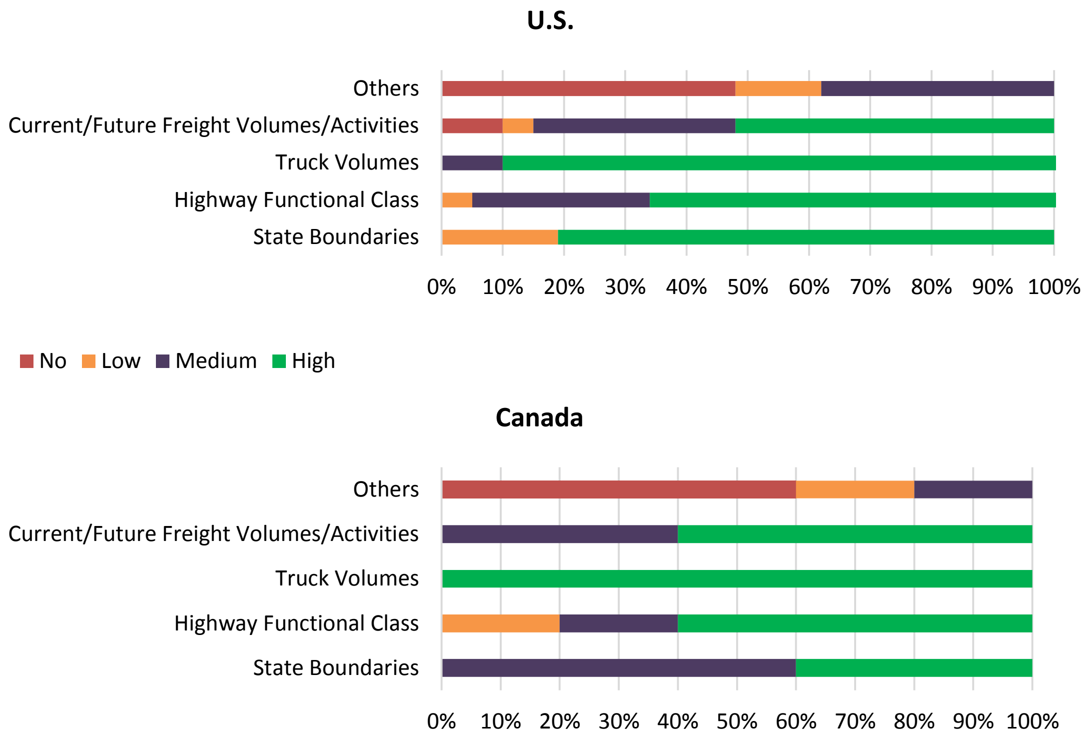


Figure 3.5 Factors influencing selection of the location for fixed weigh stations

3.3.3 Virtual Weigh Stations (VWS)

The survey results indicated that 54.5 percent of participating US states use Virtual Weigh Stations (VWS) as a strategy for commercial vehicle enforcement. Three out of the five participating Canadian provinces stated that they use VWS as a strategy.

In order to understand the main use of VWS in the US and Canada, respondents were asked to indicate the main functional applications of their VWSs. As Figure 3.6 shows, the majority of participating states and provinces use their VWS for truck size and weight enforcement as well as safety and credentialing. The results also show that a number of states and provinces use VWS for direct enforcement of commercial vehicle laws.

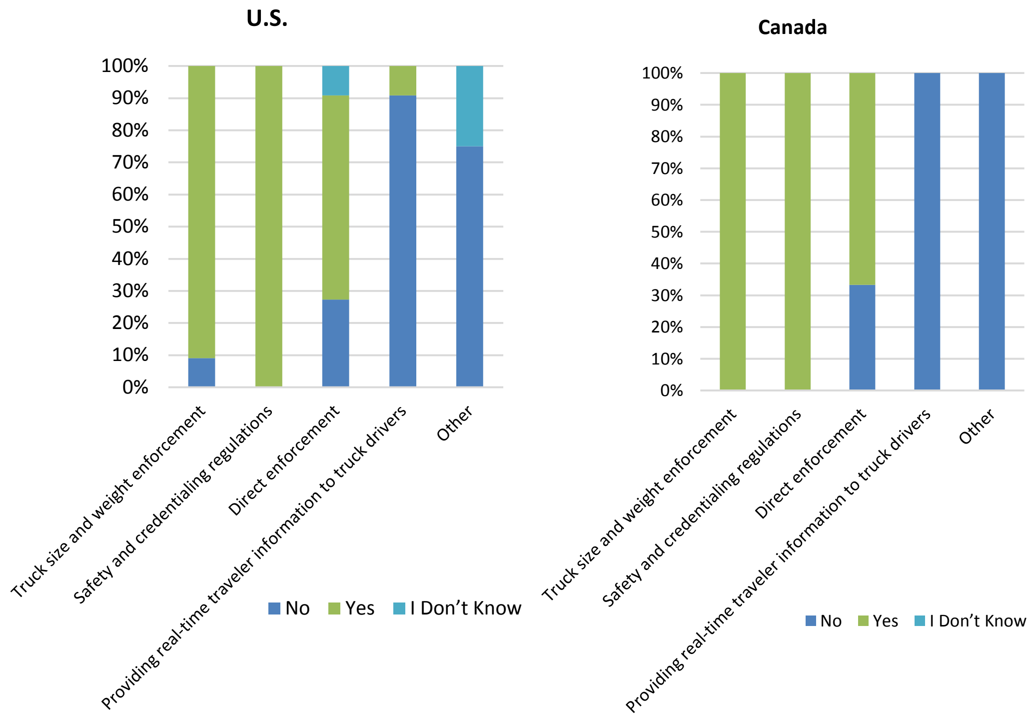
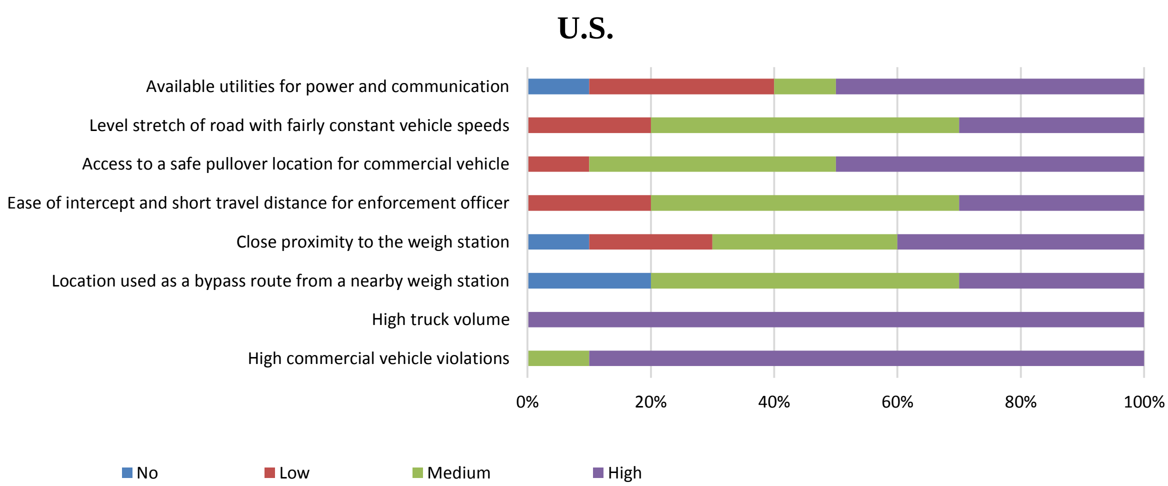


Figure 3.6 Functional applications of Virtual Weigh Stations (VWS)

For the factors influencing the decision to locate VWS, the participating US states rated high truck volume and high commercial vehicle violations as the main criteria in the selection of locations for VWSs. Other highly rated considerations include: availability of utilities for power and communication, access to a safe pullover location, and close proximity to a fixed weigh station. Figure 3.7 presents the rating for each of the factors in the US and Canada.



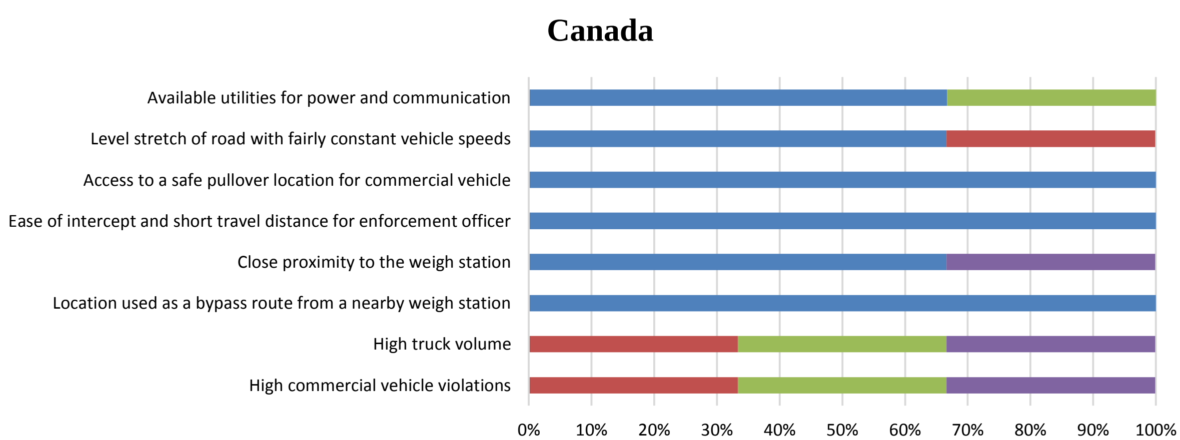


Figure 3.7 Ratings of criteria for locating Virtual Weigh Stations (VWS)

The literature review indicated that different states operate VWS with different levels of technology depending on state laws. For example, while some states allow automatic enforcement such as camera-based enforcement, others do not. Roadside technology availability determines how much a VWS can accomplish. The roadside-based technologies include Automatic Vehicle Identification (AVI) systems using Optical Character Recognition (OCR) of the license plate and DOT numbers. Out of the surveyed states using VWS, 63.6 percent indicated that they employ advanced roadside-based technologies for automatic identification of violators. For Canadian provinces using VWS, 33.3 percent indicated that they employ advanced roadside-based technologies for automatic identification of violators.

Regarding the future of VWS, 63.6 percent of responding states indicated that they plan to add more VWS in the near future. For Canadian provinces, only 33 percent indicated the desire to add more VWS in the near future.

3.3.4 Mobile Weight Enforcement using Weigh-In-Motion (WIM)

Mobile weight enforcement using WIM sites is done by patrol units in which potential weight violators are communicated in real-time to an officer stationed at the WIM site. The officer can then chase potential violators for further checks at other enforcement locations if necessary. The survey results indicated that 57.1 percent of participating US states and 80 percent of Canadian provinces participating in the survey use mobile weight enforcement strategy. Figure 3.8 shows the factors considered to locate WIM sensors for conducting mobile weight enforcement. As shown, traffic volume, particularly commercial vehicle volume was reported more frequently. Other factors included the location of a safe site in relation to the WIM site, safety of officer and ability to receive data (i.e., communication systems).

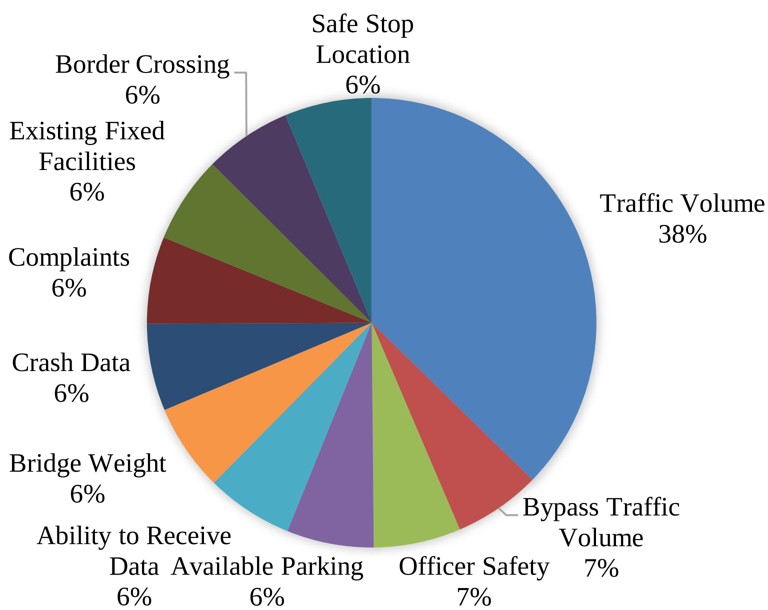


Figure 3.8 Criteria for selecting location of WIM sensor for mobile weight enforcement

3.3.5 Preclearance Systems

Preclearance systems guide truck drivers to bypass or enter the fixed weigh station as they approach the facility after their weight information and credentials are electronically checked and verified. With regard to using preclearance systems, 87.7 percent of responding US states and 60 percent of Canadian provinces participating in the survey indicated that they use pre-clearance systems in their commercial vehicle enforcement programs. Furthermore, 94.1 percent of US states and all Canadian provinces using pre-clearance systems plan to continue using or expand their electronic pre-clearance systems.

3.3.6 Check-Lane Operations

Check-lane operations are temporary operations by enforcement units that use a safe location (e.g., rest area) to inspect commercial vehicles. In Michigan, temporary signs are used to direct commercial vehicles to the enforcement site. The survey results revealed that only 23.6

percent of US states participating in the survey employ check-lane operations as a strategy for enforcing commercial vehicle laws. On the other hand, 80 percent of provinces participating in the survey indicated that they use check-lane operations. The main criteria for selecting the location for check-lane operations were truck volume and safety concerns related with commercial vehicles. Figure 3.9 presents all criteria identified by survey participants.

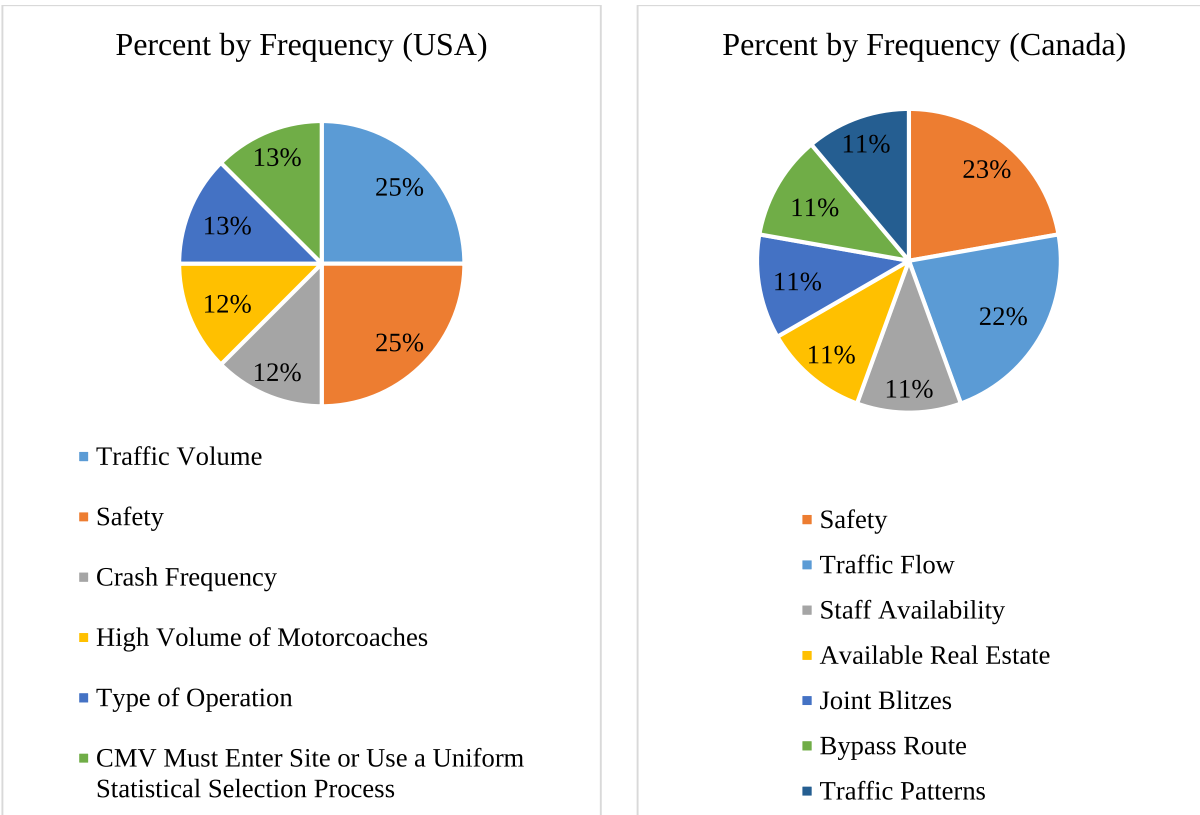
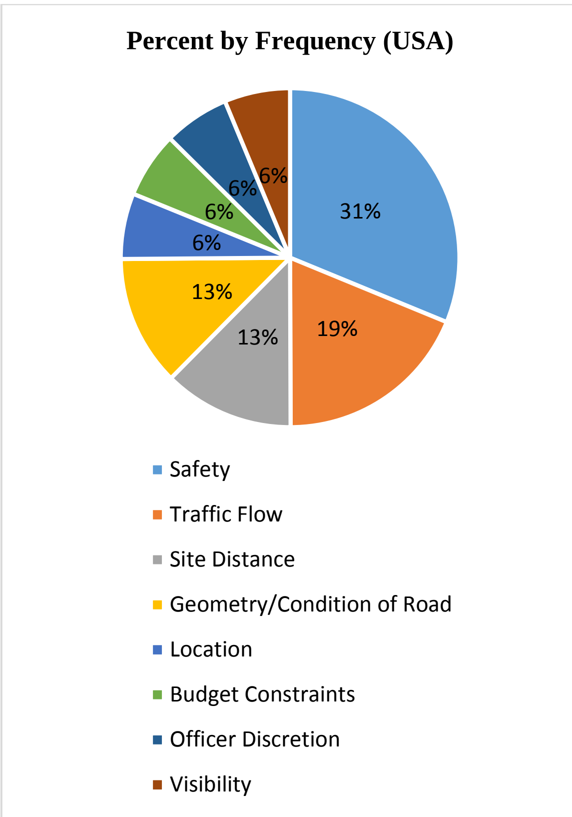


Figure 3.9 Criteria for selecting location of check-lane operations

3.3.7 Other Enforcement Strategies

In addition to the strategies discussed above, 89.5 percent of US states and all Canadian provinces participating in the survey indicated that they use safe enforcement sites such as rest areas or roadway shoulders to perform enforcement of commercial vehicles. While 80 percent of Canadian provinces participating in the survey stated that they install pavement cut-outs/notches at safe enforcement sites to facilitate the use of portable scales, only 38 percent of US states participating in the survey stated that they install pavement cut-outs/notches at safe enforcement sites. The main criteria for locating safe enforcement sites with pavement cutouts/notches were reported to be safety concerns as well as traffic flow. Figure 3.10 presents all criteria for locating safe enforcement sites with pavement cutouts/notches.



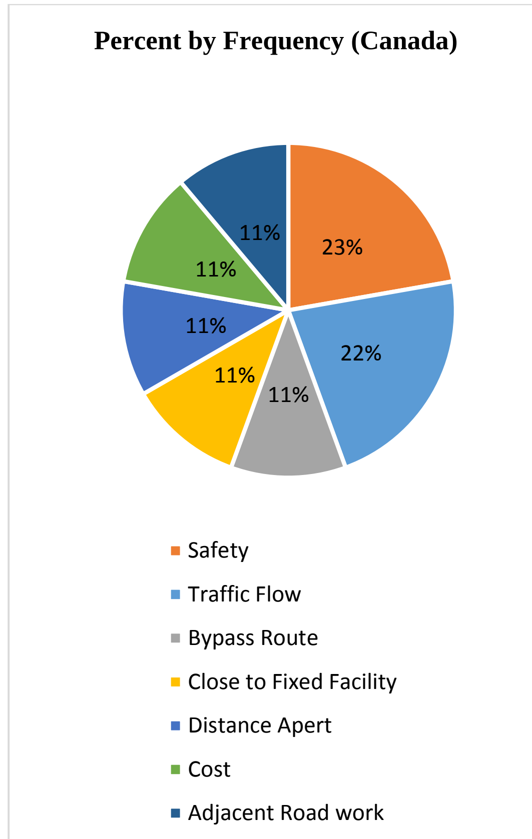


Figure 3.10 Criteria for locating safe enforcement sites with pavement cutouts/notches

3.4 Findings from the Online Survey

The survey results revealed current weight/size enforcement strategies, technologies implemented/planned in other states and selected Canadian provinces. In summary, the following were determined through the survey:

- The majority of US states (95 percent) and Canadian provinces use fixed weigh stations for commercial vehicle enforcement.
- About one-third of states and provinces participating in the survey use mainline and low-speed WIMs to improve efficiency of commercial vehicle enforcement operations.
- Safety concerns as well as changes in traffic volume have led to states and provinces to remove fixed weigh stations.
- The majority of states (85.7 percent) and provinces (60 percent) do not plan to remove fixed weigh stations in the near future.
- Two-thirds of states and provinces plan to add more fixed weigh stations in the future.
- In addition to random and/or scheduled patrol on suspected routes, portable scales and virtual weigh stations (VWS) are used to mitigate the problem of violators bypassing fixed weigh stations.
- Truck volume, state boundary, and highway functional class are the major criteria for locating fixed weigh stations.
- More than half of the participating states and provinces use virtual weigh stations to enforce commercial vehicle laws
- Truck volume, high commercial vehicle violations, availability of utilities for power and communication, access to a safe pullover location, and close proximity to the fixed weigh station are the main criteria in the selection of locations for VWSs.
- The majority of participating US states (57 percent) and Canadian provinces (80 percent) use mobile enforcement strategy.
- Preclearance systems are used in many states (87.7 percent) and Canadian provinces (60 percent).
- About a quarter of US states and 80 percent of Canadian provinces participating in the survey employ check-lane operations as a strategy for enforcing commercial vehicle laws.
- A little over a third (38 percent) of US states participating in the survey use safe enforcement sites with pavement cut-outs/notches to facilitate the use of portable scales while 80 percent of provinces participating in the survey install pavement cut-outs/notches.

3.5 Summary of the Visit to Lowell Fixed Weigh Station, Indiana

The research team visited the Lowell fixed weigh station, located along I-65 South (about 0.5 miles North of IN-2 route) in Lowell County, Indiana. The fixed weigh station has a preclearance system (PrePass) installed and is open Monday-Friday, 6 A.M. to 6 P.M. It was reported that the site experiences truck queues occasionally. The unique features observed at the fixed weigh station were the configuration of the static scales and presence of overhead screens displaying the weight of a vehicle as it is being weighed. In regards to the configuration of the static scale, it was observed that a combination of four scales is used to weigh multiple axle groups simultaneously. The axle group weights are displayed on the screens visible to the truck driver. By weighing groups of axles simultaneously, the officers save time as they can process a truck very quickly. However, weighing trucks in this way depends on whether the state weight limit requirements are based on individual axles or groups of axles.

4 MICHIGAN COMMERCIAL VEHICLE ENFORCEMENT STRATEGIES AND PERFORMANCE

4.1 Introduction

The Michigan Department of Transportation (MDOT) provides and maintains facilities and infrastructure for commercial vehicle enforcement in Michigan. The Commercial Vehicle Enforcement Division (CVED) of the Michigan State Police (MSP) uses the facilities to enforce Michigan's commercial vehicle laws. Furthermore, the CVED uses the facilities and infrastructure to conduct federal compliance reviews and investigations, school bus inspections, commercial vehicle training for division personnel as well as local and county law enforcement officers, and conducting new entrant safety audits (MSP, 2014).

Similar to other states, Michigan employs a variety of strategies to enforce commercial vehicle laws. These include the use of fixed weigh stations; the use of portable scales; the use of wireless Weigh-In-Motion (WIM) and permanent intermittent truck weigh stations (PITWS) during mobile screening operations; and check-lane operations at designated areas such as rest areas. While a number of fixed weigh stations have basic features needed to enforce commercial vehicle weight laws (such as a static scale), others have improvements and enhancements designed to increase efficiency of enforcement activities. These enhancements include the use of bypass lanes supported by a low-speed WIM installed on the ramp to sort vehicles, as well as installation of preclearance systems which allow a number of subscribed and compliant commercial vehicles to bypass the fixed weigh stations. These improvements reduce the number of commercial vehicles required to enter the fixed weigh station and allow CVED to focus on commercial vehicles which are potentially non-compliant. Additional improvements include the use of over-height detectors (OHD), variable message signs (VMS) to direct traffic, and use of cameras. Cameras are beneficial to determine when back-ups are extending into the freeway. In some instances, the cameras can be used to check if commercial vehicles are utilizing the shoulder to park when trying to avoid entering a fixed weigh station.

Details of Michigan's commercial vehicle enforcement strategies were obtained through review of existing MDOT and MSP reports as well as physical site visits. To gain a greater understanding, the research team conducted site visits to five fixed weigh stations in Michigan and one fixed weigh station in Indiana. Also, the research team attended one mobile enforcement operation and one check-lane operation. The following sections discuss Michigan commercial vehicle enforcement strategies.

4.2 Conditions of Existing Enforcement Facilities in Michigan

4.2.1 Fixed Weigh Stations in Michigan

The Michigan Department of Transportation (MDOT) currently maintains 15 fixed weigh stations (FWS) and a number of WIM sites along freeways and other state routes (see Figure 4.1). Weigh stations were built along public roads to protect the public investment in infrastructure from premature deterioration caused by overweight trucks. Weigh stations have been around for decades and can likely be traced back to when roads were beginning to be paved and trucks were used to move cargo over short distances. The majority of these weigh stations were built in the 1960's, prior to the significant growth of Michigan's economy and interstate trucking. The following are the details of all fixed weigh stations in Michigan.

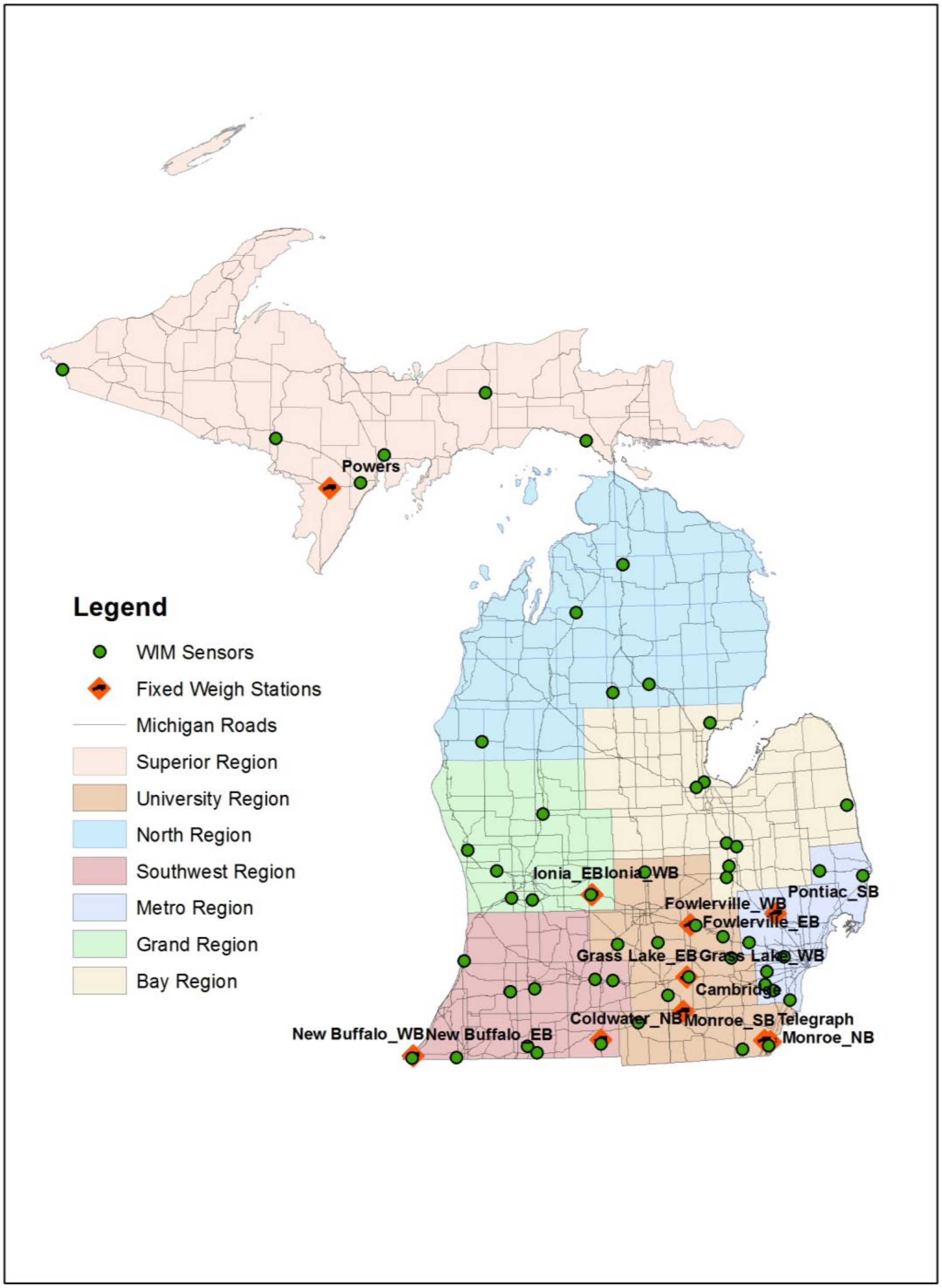


Figure 4.1 Location of Fixed Weigh Stations and WIM sites in Michigan

Powers Fixed Weigh Station

Powers fixed weigh station is located in the MDOT Superior Region. One weigh station is provided at this site at the intersection of US-2 and US-41 in Menominee County. The weigh station is provided on the northeast corner of the intersection and monitors all directions on both roads. This station is considered a border station, where US-41 services regional commercial traffic, and US-2 services national and international commercial traffic. An aerial view of the station is shown in Figure 4.2.

Operations are classified as being basic at this station. In 2010, the static deck was upgraded. The static scale is located in front of the building adjacent to the parking lot where inspections are conducted when necessary. New variable message signs to display move forward/back/stop instructions and a wireless open/close sign were installed in 2011. These improvements have cost approximately $254, 000 between 2008 and 2011. The fixed weigh station is in good condition and no improvements are needed to the base condition.

Source: Bing Maps

Figure 4.2 Layout of Powers Weigh Station

Cambridge Fixed Weigh Station

The Cambridge station is located in the MDOT University Region. One weigh station is provided at this site at the intersection of M-50 and US-12 in Lenawee County. The weigh station is provided on the southwest corner of the intersection and monitors all directions on both roads. M-50 services regional commercial traffic, and US-12 services statewide commercial traffic. An aerial view of the station is shown in Figure 4.3.

The static scale is located in front of the building adjacent to the parking lot where inspections are conducted when necessary. In 2010, the static deck, pavement, and signs were upgraded. New variable message signs were installed in 2010 to display move forward/back/stop instructions. In 2011, wireless open/closed signs were installed. These improvements cost approximately $376,000 between 2008 and 2011. The fixed weigh station is in good condition and no improvements are needed to the base condition.

During the site visit, operations were observed to be very basic. Trucks are required to drive slowly over the static scale. During the pass through, a level 3 inspection is conducted, where an officer checks the truck for safety requirements e.g. seat belt, headlights, and tires. If the truck meets weight and safety requirements they are allowed to proceed towards exiting the station. If a truck is suspected as overweight during the pass through, the truck is required to stop and back-up to be reweighed per axle. During this process, trucks are required to wait and the queue may begin to back up onto the main road. If this occurs, the weigh station is wirelessly closed. During this time, overweight trucks could go unmonitored. The parking lot is utilized to park overweight trucks, and conduct safety inspections. Such inspections and axle weighing were observed during the site visit.

Source: Google Maps

Figure 4.3 Layout of Cambridge Weigh Station

Fowlerville Fixed Weigh Stations

The Fowlerville station is located in the MDOT University Region. There are two weigh stations at this site, located on I-96 between US-127 and US-23 in Livingston County. I-96 services national and international traffic, therefore this section of roadway experiences high commercial traffic. An aerial view of both stations is shown in Figure 4.4.

The weigh stations were constructed shortly after I-96 was built in the 1960s. One station monitors westbound traffic and the other monitors eastbound traffic. The layouts of both stations are identical. Very basic technology is being utilized for a weigh station that experiences high commercial traffic. A static scale similar to the one in Cambridge is being utilized to weigh trucks.

No improvements have been made to these weigh stations between 2008 and 2013, although a non-wireless WIM two miles east of the weigh station has been relocated requiring diamond grinding of pavement, costing $25,000.

Source: Google Maps

Figure 4.4 Layout of Fowlerville Weigh Station

Telegraph Fixed Weigh Station

The Telegraph weigh station is located in the MDOT University Region. One weigh station is provided at this site, located in the median on US-24 in Erie County, 6.6 miles south of M-50. The weigh station monitors both northbound and southbound directions on US-24. US-24 services regional commercial traffic and runs parallel with I-75. An aerial view of the station is shown in Figure 4.5.

Very basic technology is being utilized at this station. Only one static scale is provided, located on the east side of the building. The MDOT 2012 condition assessments states that the weigh station is in need of improvement and the static scales need to be replaced. No improvements have been made to these weigh stations between 2008 and 2013. The weigh station operates with the highest hourly operating cost ($37/hour), compared to the other fixed weigh stations.

Source: Google Maps

Figure 4.5 Layout of Telegraph Weigh Station

Pontiac Fixed Weigh Station

The Pontiac station is located in the MDOT Metro Region. There is one weigh station at this site, located on I-75 between US-24 and M-59 in Oakland County. The station monitors southbound I-75 commercial traffic. I-75 services national and international traffic, therefore this section of roadway experiences high commercial traffic. A vacant overgrown lot is located on northbound I-75, where a weigh station was previously present. An aerial view of the site is shown in Figure 4.6.

The weigh station was constructed shortly after I-75 was built in the 1960s. Operations are classified as being basic. The static scale is located in front of the building. In 2012, the static deck and pavement including 100 feet of the approaches were upgraded. New variable message signs were installed in 2012 to display move/back/stop instructions and speed limits. A new camera, speakers, signals, and wireless open/close signs were also installed. These improvements cost approximately $749,000 between 2010 and 2012. The fixed weigh station is in good condition and no improvements are needed to the base condition.

Source: Google Maps

Figure 4.6 Layout of Pontiac Weigh Station

Ionia Fixed Weigh Station

The Ionia station is located in the MDOT Grand Region. There are two weigh stations at this site, located on I-96 just east of M-66 in Ionia County. One station monitors westbound traffic and the other monitors eastbound traffic. The layouts of both stations are identical. I-96 services national traffic. An aerial view of both stations is shown in Figure 4.7.

In 1997, new static decks were installed at each of the weigh stations. The static scale is located in front of the building. Infrastructure was improved in 2012 by repairing ramps, full depth concrete joints, and resurfacing shoulders. These improvements cost nearly a total of $579,000 at both of the weigh stations.

During the site visit, operations were observed at the eastbound station. Trucks are required to drive slowly over the static scale. During the pass through, a level 3 inspection is conducted, where an officer checks the truck for safety requirements e.g. seat belt, headlights, and tires. If the truck meets weight and safety requirements they are allowed to proceed back onto the freeway. If a truck is suspected as overweight during the pass through, the truck is signaled to drive back around the building to be re-weighed on the static scale. During this process, the weigh station may be wirelessly closed to prevent trucks from backing up onto the freeway. During this time, overweight trucks could go unmonitored.

Source: Google Maps

Figure 4.7 Layout of Ionia Weigh Station

Grass Lake Fixed Weigh Stations

The Grass Lake station is located in the MDOT University Region. There are two weigh stations at this site, located on I-94 between US-127 and M-52 in Jackson County. I-94 services national and international traffic, therefore this section of roadway experiences very high commercial traffic. An aerial view of both stations is shown in Figure 4.8.

The weigh stations were constructed shortly after I-94 was built in the 1960s. The buildings were added later on in the early-1990s. One station monitors westbound traffic and the other monitors eastbound traffic. The layouts of both stations are identical. The static scale is located in front of the building adjacent to the bypass lane. Variable message signs display speed limits, and move forward/back/stop instructions. Cameras are provided in both directions to monitor backups onto the freeway.

In 2013, the ramps, parking lots, static deck, and the low speed WIM system were reconstructed at both sites. New by-pass lanes, variable message signs, and wireless open/closed signs were also installed. These improvements cost a total of approximately $2,249,000 for both sites.

Source: Google Maps

Figure 4.8 Layout of Grass Lake Weigh Stations

Coldwater Fixed Weigh Station

The Coldwater station is located in the MDOT Southwest Region. There is one weigh station at this site, located on I-69 between US-12 and the Indiana border in Branch County. The station monitors northbound I-69 commercial traffic. This station is considered a border station, where I-69 services national traffic. An aerial view of the site is shown in Figure 4.9.

The weigh station was constructed in the early 1980s. As of the 2012 MDOT condition assessment, the infrastructure was in poor condition and the static scale had been removed due to rusting. In 2009 pavement maintenance was performed. In 2013 the weigh station was fully reconstructed by replacing the static scale, ramps, inspection area, installing new variable message signs and speed limit signs, speakers, and a low-speed WIM with a bypass lane. The layout is now identical to the Grass Lake Fixed Weigh Station. These improvements cost approximately $2,741,000 between 2009 and 2013.

Source: U.S. Geological Survey (USGS)

Figure 4.9 Layout of Coldwater Weigh Station

New Buffalo Fixed Weigh Station

The New Buffalo station is located in the MDOT Southwest Region. There are two weigh stations at this site, located on I-94 less than three miles north of the Indiana border in Berrien County. One station monitors westbound traffic and the other monitors eastbound traffic. I-94 services national and international traffic, therefore this section of roadway experiences high commercial traffic. An aerial view of both stations is shown in Figure 4.10. The layouts of the two weigh stations are slightly different from one another.

The westbound weigh station was constructed in the mid-1990s. A new operational WIM was installed in 2002. Variable message signs were installed in 2009 to display speed limits, and move forward/back/stop instructions. Cameras are provided to monitor backups onto the freeway. The static scale is located in the back of the building, which may reduce efficiency because trucks have to travel longer distances at very low speed.

The eastbound weigh station was constructed in 2002, with an operational WIM. PrePass was installed in November 2009 to help alleviate the high commercial traffic entering the weigh station. Variable message signs were also installed in 2009 to display speed limits, and move forward/back/stop instructions. Cameras are provided to monitor backups onto the freeway. The static scale is located in the front of the building, adjacent to the bypass lane.

Similar improvements have been made to both of the weigh stations at this location, including installing municipal water service, and infrastructure improvements mentioned above. These improvements took place from 2009 to 2014 and cost a total of approximately $1,124,000. The MDOT 2012 condition assessments states that the concrete is acceptable and that the back lots are in acceptable conditions. The open/closed wireless sign is in need of improvement. These concerns have been addressed in the 2014 construction year, therefore no improvements to the existing infrastructure are suggested at this time. Although, reconfiguration of the westbound weigh station is suggested in the future to match the eastbound weigh station configuration.

During the site visit, operations were observed at the eastbound station. Trucks that do not have PrePass are required to enter the station, although some PrePass owners (about one in five) may also be required to enter depending on the signal received from the transmitter. Trucks enter the station at approximately 25 mph, which can be varied based on traffic patterns to reduce delay. The trucks are then sorted by a load cell WIM. If the truck is suspected as being overweight, the signals direct them to the right lane, where the static scale is located in front of the building. Otherwise, if trucks meet weight requirements, there is very little delay as they utilize the bypass lane to proceed back onto the freeway.

Source: Google Maps

Figure 4.10 Layout of New Buffalo Weigh Station

Monroe Fixed Weigh Station

The Monroe station is located in the MDOT University Region. There are two weigh stations at this site, located on I-75 in Monroe County, approximately seven miles north of the Ohio border. The I-75 freeway services national and international traffic. An aerial view of both stations is shown in Figure 4.11.

The weigh stations were constructed in the mid-1980s. One station monitors northbound traffic and the other monitors southbound traffic. The northbound station is a state of the art weigh station that includes an inspection building where Level 1 inspections can be conducted. The northbound station also experiences the highest volume of commercial traffic in the state. The MDOT 2012 condition assessments states that improvements have been recently made to the infrastructure. PrePass was installed at the northbound station in 2010 to alleviate the high commercial vehicle traffic entering the weigh station. The layouts of both stations are identical. In 2011, a new static scale, load cell WIM, and variable message signs were installed. Variable message signs display speed limits, and move forward/back/stop instructions. Cameras are provided in both directions to monitor backups onto the freeway. The static scale is located in the back of the building. The improvements took place from 2010 to 2013 and cost a total of approximately $2,069,000.

During the site visit, operations were observed at the northbound station. Trucks that do not have PrePass are required to enter the station, although some PrePass owners may also be required to enter depending on the signal received. Trucks enter the station at approximately 25 mph, which can be varied based on traffic patterns to reduce delay. The trucks are then sorted by a load cell WIM. If the truck is suspected as being overweight, the signals direct them to go right, towards the back of the building where the static scale is located (which may reduce efficiency because trucks have to travel longer distances at very low speed). The officer uses a different work station on the other side of the building to operate the static scale which may increase delay. Otherwise, if trucks meet weight requirements, there is very little delay as they proceed back onto the freeway.

Source: Google Maps

Figure 4.11 Layout of Monroe Weigh Station

Summary of existing physical condition

Table 4.1 presents a summary of existing physical condition needs for all fixed weigh stations in Michigan while Table 4.2 shows the detailed traffic and scheduled operation hours for each fixed weigh station.

Table 4-1 Existing physical condition needs for fixed weigh stations

Weigh Station	Physical Condition Needs
New Buffalo_EB	No improvements, structure is in good condition
Monroe_NB	No improvements, was recently upgraded (2011)
New Buffalo_WB	No improvements, structure is in good condition
Monroe_SB	No improvements, was recently upgraded (2011)
Grass Lake_EB	No improvements, was recently upgraded (2013)
Grass Lake_WB	No improvements, was recently upgraded (2013)
Coldwater_NB	No improvements, was recently upgraded (2013)
Ionia_WB	Replace and reconstruct weigh station, excluding the ramps
Ionia_EB	Replace and reconstruct weigh station, excluding the ramps
Fowlerville_EB	Replace and reconstruct weigh station
Fowlerville_WB	Replace and reconstruct weigh station
Powers	No improvements, was recently upgraded (2010/2011)
Pontiac_SB	No improvements, was recently upgraded (2012)
Telegraph	Repair and replace concrete, pavement markings, etc.
Cambridge	No improvements, was recently upgraded (2011)

Table 4-2 Details of traffic and scheduled operation hours for each fixed weigh station

Weigh Station	Region/Location	Scale Location	CADT	AADT	Scheduled Operational Hours per Week	Weekends
New Buffalo_EB	Southwest /I-94 EB	Front	10500	40800	Avg. 120 hours	Intermittent weekends
Monroe NB	University/I-75 NB	Back	14800	56400	Avg. 120 hours	Intermittent weekends
New Buffalo_WB	Southwest /I-94 WB	Back	10500	40800	Avg. 50 hours	No
Monroe_SB	University/I-75 SB	Back	14800	56400	Avg. 90 hours	No
Grass Lake_EB	University/I-94 EB	Front	7700	43100	Avg. 80 hours	Intermittent weekends
Grass Lake_WB	University/I-94 WB	Front	7700	43100	Avg. 80 hours	Intermittent weekends
Coldwater_NB	Southwest/I-69 NB	Front	5300	19300	Avg. 25 hours	No
Ionia_WB	Grand/I-96 WB	Front	4400	35500	Avg. 50 to 70 hours	No
Ionia_EB	Grand/I-96 EB	Front	4400	35500	Avg. 50 to 70 hours	No
Fowlerville_EB	University/I-96 EB	Front	4600	46800	Avg. 60 hours	Intermittent weekends
Fowlerville_WB	University/I-96 WB	Front	4600	46800	Avg. 60 hours	Intermittent weekends
Powers	Superior/US41 & US2	Front	325	5050	Avg. 16-24 hours	No
Pontiac_SB	Metro/I-75 SB	Front	3600	78300	Avg. 20-30 hours	No
Telegraph	University/US-24	Front	240	7000	Avg. 5 hours	No
Cambridge	University/ M50 & US12	Front	260	5300	Avg. 20 hours	No

Levels of Fixed Weigh Stations

Based on site visits as well as review of the existing conditions of Michigan fixed weigh stations, it was determined that four levels of fixed weigh stations can be established for analysis purposes: Basic, Intermediate, Advanced and Most Advanced. The main distinguishing features were mainline WIM, low-speed WIM with bypass, and preclearance system. A basic fixed weigh station has only a static scale, while an intermediate fixed weigh station consists of both a static scale and a mainline WIM. The basic and intermediate fixed weigh station may also have additional features such as camera, and variable message signs (VMS). The advanced fixed weigh station consists of a low-speed WIM for sorting traffic as well as a bypass lane, in addition to the features present at intermediate stations. At the highest level, the most advanced fixed weigh station consists of all features of the advanced level, plus a preclearance system. Table 4.3 presents a summary of the features by level while Table 4.4 shows the levels assigned to all Michigan fixed weigh stations.

Table 4-3 Features of fixed weigh stations by level

Basic	Intermediate	Advanced	Most Advanced
Static Scale	Static Scale	Static Scale	Static Scale
-	-	Low Speed WIM	Low Speed WIM
-	Mainline WIM	Mainline WIM	Mainline WIM
-	-	Bypass Lane	Bypass Lane
-	-	-	PrePass
-	-	OHD	OHD
Camera	Camera	Camera	Camera
Moveforward VMS	Moveforward VMS	Moveforward VMS	Moveforward VMS
Speed VMS	Speed VMS	Speed VMS	Speed VMS

Table 4-4 Levels of existing fixed weigh stations in Michigan

No.	Weigh Station	Highway	Bypass Lane	Low-Speed WIM	Mainline WIM	PrePass	OHD	Camera	VMS-MoveForward	VMS-Speed Limit	Rank	Level
1	New Buffalo_EB	I-94 EB	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	1	Most Advanced
2	Monroe_NB	I-75 NB	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	1	Most Advanced
3	New Buffalo_WB	I-94 WB	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	2	Advanced
4	Monroe_SB	I-75 SB	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	2	Advanced
5	Grass Lake_EB	I-94 EB	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	2	Advanced
6	Grass Lake_WB	I-94 WB	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	2	Advanced
7	Coldwater_NB	I-69 NB	Yes	Yes	Yes	No	Yes	No	Yes	Yes	2	Advanced
8	Ionia_WB	I-96 WB	No	No	Yes	No	No	No	No	No	3	Intermediate
9	Ionia_EB	I-96 EB	No	No	Yes	No	No	Yes	No	No	3	Intermediate
10	Fowlerville_EB	I-96 EB	No	No	Yes	No	No	No	No	No	3	Intermediate
11	Fowlerville_WB	I-96 WB	No	No	Yes	No	No	No	No	No	3	Intermediate
12	Powers	US-41 & US-2	No	No	No	No	No	No	Yes	No	4	Basic
13	Pontiac_SB	I-75 SB	No	No	No	No	No	Yes	Yes	No	4	Basic
14	Telegraph_NB_SB	US-24 NB & SB	No	No	No	No	No	No	No	No	4	Basic
15	Cambridge	M-50 & US-12	No	No	No	No	No	No	Yes	No	4	Basic

4.2.2 Safe Enforcement Check Lane

Depending on the region, check lanes are usually conducted for one week during a month, at different locations in each month. The research team observed a check lane that was conducted in the vacant rest area on eastbound I-196 in Zeeland. Figure 4.12 shows truck safety inspection conducted during site visit. Five signs are posted on the main road directing commercial vehicles to enter the vacant rest area. Trucks are required to enter the check lane. Officers generally focus on inspecting the safety conditions of the commercial vehicles. If a truck is suspected to be overweight, officers utilize the pavement cut-out (if available) for convenient use of the portable scales. The list of current safe enforcement sites used for check lane operations is presented in Appendix 4.1, which also shows the fines issued at these sites for years 2010-2012.

Figure 4.12 Check lane operation (Zeeland EB I-196)

During a check lane operation, all trucks are required to enter the site. This has the potential to create queue backups which could extend to the mainline and disrupt/disturb traffic flow upstream the site. Such backup could lead the general traffic to avoid using the rest area. During the site visit at the rest area in Zeeland, the research team observed regular queue backups which forced the officers to allow trucks to proceed through the rest area. Figure 4.13 shows one of the queue backups observed at the rest area in Zeeland.

Figure 4.13 A queue backup of trucks onto the mainline at a check-lane operation

4.2.3 Mobile Screening Operation

The research team observed operations of a mobile screening enforcement in Paw Paw, Michigan. The law enforcement officer connects wirelessly to the WIM using a laptop computer. Once a commercial vehicle is identified to be overweight, the information is displayed on the officer's laptop. Then, if the officer can visually identify the truck associated with the data displayed on the laptop, s/he directs the truck operator to a nearby inspection lot. During the observation in Paw Paw (Figure 4.14), a safe enforcement site with pavement cut-out for using portable scales was located within 15 miles of the high-speed WIM site. The use of the cut-out was found to be extremely beneficial, reducing the time to weigh a truck from one hour to approximately twenty minutes.

(a) Escorting the potential overweight truck to a nearby safe enforcement site

(b) Weighing and inspecting the truck

Figure 4.14 Mobile screening operation (Paw Paw, Michigan)

4.3 Costs to Upgrade Existing Fixed Weigh Stations

Analysis of the costs needed to upgrade each of the existing fixed weigh stations was estimated depending on their current conditions. MDOT reports on previous upgrade costs as well as other sources of cost information were utilized. Table 4-5 presents a summary of costs needed to upgrade each of the fixed weigh stations.

Table 4-5 Costs to upgrade existing fixed weigh stations

Weigh Station	2015 Base Cost	2015 Operating Cost	Annual Labor Cost	Annual Maintenance Cost	Upgrade to Intermediate	Upgrade to Advanced	Upgrade to Most Advanced
New Buffalo_EB	$0	$15,726	$287,789	$41,000	$0	$0	$0
Monroe_NB	$0	$47,584	$287,789	$35,000	$0	$0	$0
New Buffalo_WB	$0	$30,145	$119,912	$41,000	$0	$0	$60,347
Monroe_SB	$0	$29,876	$215,842	$46,000	$0	$0	$60,347
Grass Lake_EB	$0	$26,787	$191,859	$33,000	$0	$0	$60,347
Grass Lake_WB	$0	$19,439	$191,859	$33,000	$0	$0	$60,347
Coldwater_NB	$0	$7,006	$57,558	$36,000	$0	$0	$60,347
Ionia_WB	$1,170,905	$22,635	$143,894	$15,000	$0	$686,676	$747,023
Ionia_EB	$1,170,905	$22,635	$143,894	$15,000	$0	$686,676	$747,023
Fowlerville_EB	$1,856,905	$28,337	$143,894	$15,000	$0	$686,676	$747,023
Fowlerville_WB	$1,856,905	$28,337	$143,894	$15,000	$0	$686,676	$747,023
Powers	$0	$8,337	$47,965	$6,000	$0	NA	NA
Pontiac_SB	$0	$9,088	$59,956	$15,000	$136,000	822,676	$883,023
Telegraph	$500,489	$10,615	$11,991	$15,000	$0	NA	NA
Cambridge	$0	$8,337	$47,965	$8,000	$0	NA	NA

4.4 Citation Fine Records

During commercial vehicle enforcement, law enforcement officers issue citations to violators of Michigan commercial vehicle laws. Table 4-6 presents the record of citation fines at existing fixed weigh stations for years 2010-2012. Citation fines at checklane enforcement sites are shown in Appendix 4.1, while the fines at other enforcement sites are shown in Appendix 4.2. Table 4-7 presents the total number of citations and citation fines by MSP districts.

Table 4-6 Citation fines for each fixed weigh station (2010-2012)

Year		**2010**	**2011**	**2012**
Weigh Station	**Region**	**Citation Fines**	**Citation Fines**	**Citation Fines**
New Buffalo_EB	Southwest	$328,000	$233,000	$266,000
Monroe_NB	University	$474,000	$23,000	$825,000
New Buffalo_WB	Southwest	$55,000	$24,000	$20,000
Monroe_SB	University	$41,000	$20,000	$247,000
Grass Lake _EB	University	$19,000	$0	$280,000
Grass Lake_WB	University	$16,000	$0	$218,000
Coldwater_NB	Southwest	$225,000	$92,000	$59,000
Ionia_WB	Grand	$127,000	$86,000	$29,000
Ionia_EB	Grand	$30,000	$31,000	$27,000
Fowlerville_EB	University	$10,000	$11,000	$37,000
Fowlerville_WB	University	$87,000	$74,000	$116,000
Powers	Superior	$16,000	$78,000	$41,000
Pontiac_SB	Metro	$60,000	$37,000	$111,000
Telegraph	University	$57,000	$31,000	$40,000
Cambridge	University	$2,000	$6,000	$102,000
Totals		**$1,547,000**	**$746,000**	**$2,418,000**

Table 4-7 Citation fines and number of citations by MSP districts (2010-2012)

District	**2010**		**2011**		**2012**	
	Citations	**Fines**	**Citations**	**Fines**	**Citations**	**Fines**
1	2,231	$513,000	2,171	$578,000	10,980	$1,265,000
2	1,027	$1,928,000	2,735	$918,000	1,639	$2,319,000
3	2,050	$507,000	1,660	$256,000	2,311	$470,000
5	4,729	$1,106,000	3,775	$563,000	3,918	$510,000
6	1,620	$390,000	1,573	$298,000	1,227	$236,000
7	1,252	$327,000	1,166	$278,000	650	$162,000
8	1,252	$264,000	1,289	$256,000	1,040	$223,000

4.5 Overweight Trucks

Quantifying the percentage of overweight commercial vehicles was very essential to analysis of benefits and disbenefits. This was accomplished through analysis of Michigan's WIM data provided by MDOT. MDOT maintains a number of WIM sensors throughout the state roadway network. Some of these WIM sites are in the vicinity of enforcement facilities such as fixed weigh stations. MDOT archives WIM data collected from these sites. The continuous data set consisted of eight years from (2006-2013) for all 54 weigh in-motion (WIM) stations located throughout the entire state of Michigan over the period. The WIM data contains axle weights and axle spacing for all commercial vehicles. Using the Michigan vehicle code, an algorithm was developed to identify which axle exceeded the legal state limit, and by how many pounds. Figure 4.15 shows the flow chart for the algorithm.

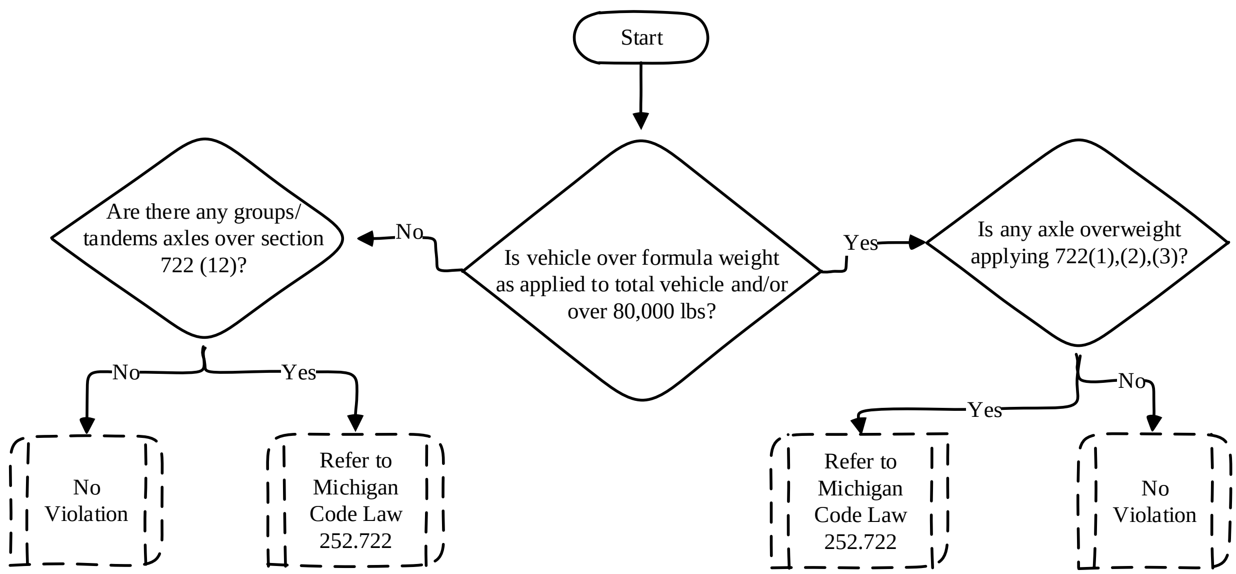


Figure 4.15 Flowchart of Michigan commercial vehicle code

Analysis of processed WIM data was accomplished utilizing Geographic Information Systems (GIS) software, Microsoft Excel, STATA and other statistical analysis software. A vehicle was categorized as overweight if the axle weight exceeded the legal limit by at least 2.5 percent. Figure 4.16 shows the percentage of overweight trucks observed each year. Overall, there is a decreasing trend in the percentage of potential overweight commercial vehicles.

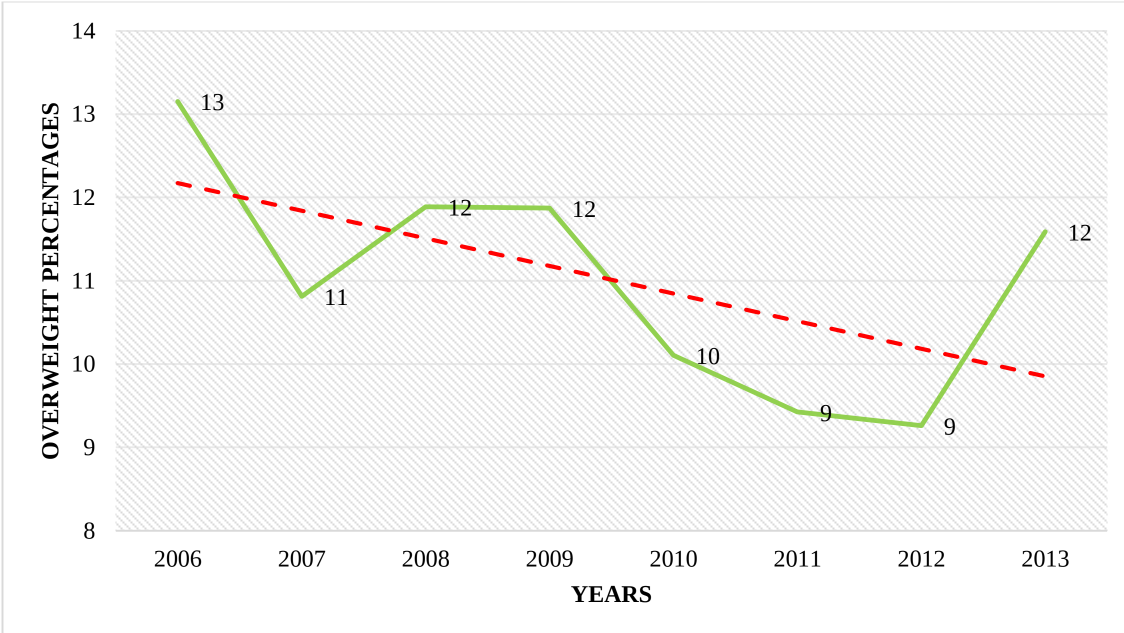


Figure 4.16 Michigan potential overweight percentage trend (2006-2013)

By analyzing data from WIM stations upstream of fixed weigh stations, the average potential overweight trucks was determined for each level of fixed weigh stations. Table 4-8 presents the observed percent of potential overweight trucks by level of fixed weigh station.

Table 4-8 Potential overweight percentage at four levels of fixed weigh stations

Level	**Potential Overweight Trucks (%)**
Most Advanced	9%
Advanced	9%
Intermediate	8%
Basic	10%
Average Potential Overweight Trucks	**9%**

The results gathered from the WIM data analysis provided an overall perspective of the potential overweight situation in the state and can help to identify locations with high number of potential weight violators. Figure 4.17 presents a color coded map showing the percentage of potential overweight trucks for each WIM site analyzed.

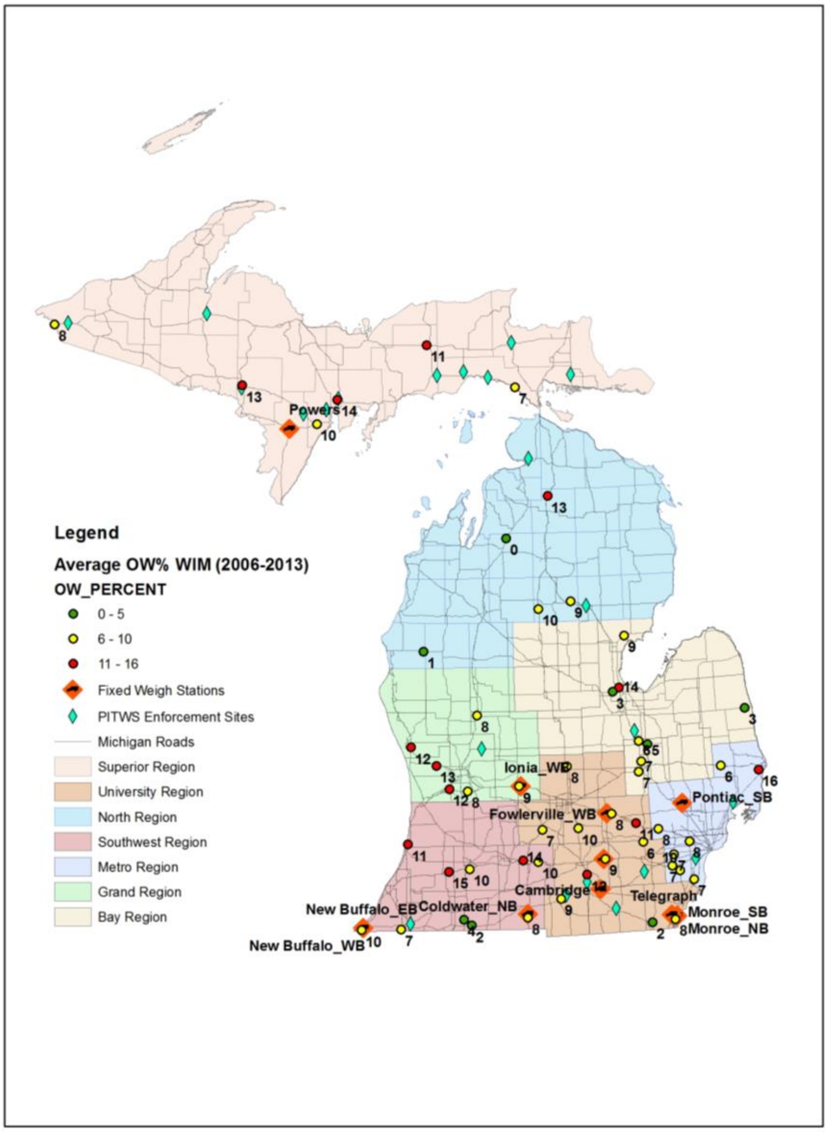


Figure 4.17 Recorded overweight percentages by WIM site

To account for variances in total, legal, and overweight trucks in different areas of the state, WIM data was also evaluated by region. The state of Michigan is divided into seven MDOT region. Table 4-9 shows the percentage distribution of total trucks by MDOT regions and axle groups.

This information was essential for estimating pavement damage since the distribution of commercial vehicles associated with potential overweight of each type was critical to estimating the amount of pavement loading saved through commercial vehicle enforcement.

Table 4-9 Total truck percentage distribution by number of axles and by MDOT regions

Region	Percentage of trucks by number of axles										
	2-axles	3-axles	4-axles	5-axles	6-axles	7-axles	8-axles	9-axles	10-axles	11-axles	Total
Bay	3%	7%	8%	65%	4%	4%	2%	3%	2%	4%	100%
Grand	5%	9%	8%	63%	4%	3%	1%	2%	1%	3%	100%
Metro	3%	6%	5%	71%	4%	3%	1%	2%	1%	4%	100%
North	8%	10%	12%	43%	5%	5%	3%	4%	3%	6%	100%
Southwest	2%	3%	4%	85%	2%	1%	0%	1%	0%	1%	100%
Superior	5%	10%	8%	47%	7%	5%	6%	3%	3%	8%	100%
University	3%	5%	6%	73%	3%	3%	1%	1%	1%	3%	100%

For example, the Southwest region showed the highest percentage (85 percent) for 5 axle trucks out of the total trucks observed in that region. Similarly, the Superior region had the highest percentage of 11-axle trucks (8 percent). In a similar manner, the distribution of overweight commercial vehicles by region and number of axles was obtained (see Figure 4.18). As shown in the figure, while commercial vehicles with five axles comprise the majority of truck traffic in all regions, there are relatively few overweight trucks with five axles. Trucks with nine, ten or eleven axles exhibited relatively higher proportions of overweight trucks. Also, the figure indicates that a large proportion of trucks with three axles are overweight compared to those with two or four axles.

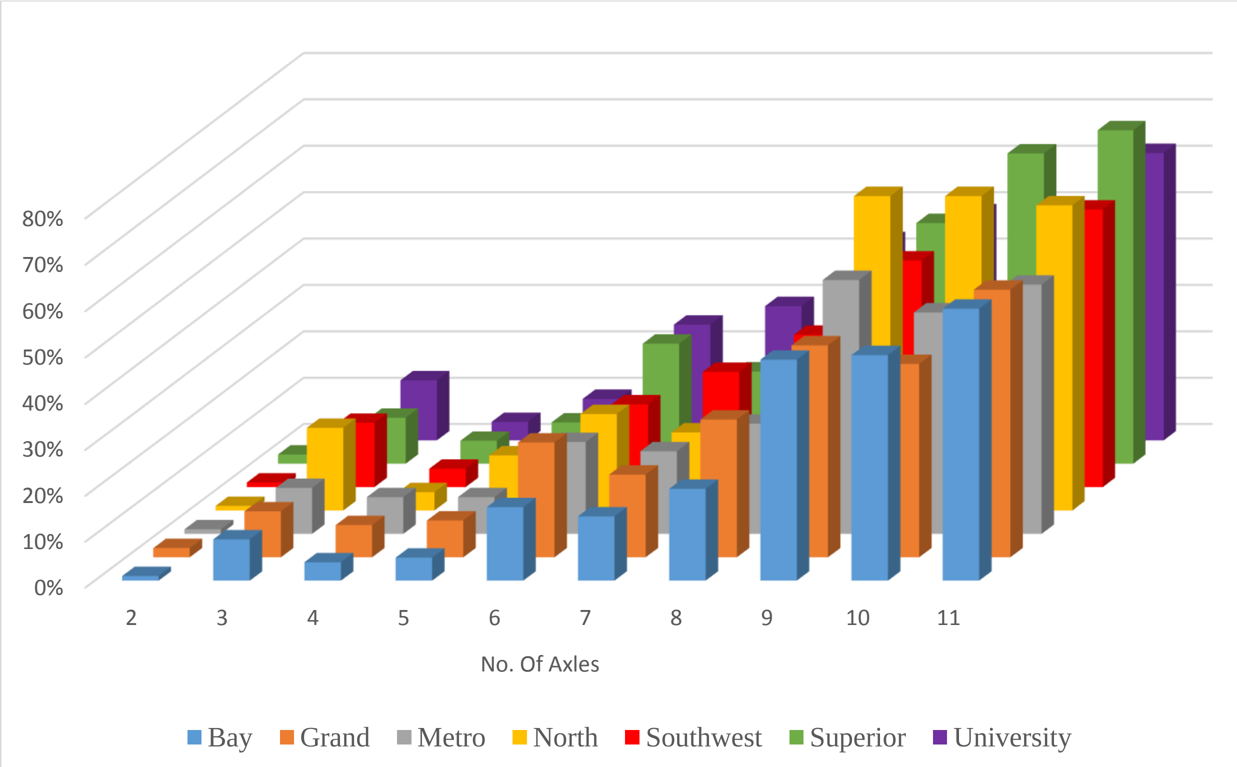


Figure 4.18 Percentages of overweight trucks by region and number of axles

4.6 Potential Bypass Routes

One of the limitations of fixed weigh stations is that they can be easily avoided by potential overweight trucks. With today's advances in communication technology, truck drivers may be able to know as soon as a fixed weigh station along their route is open. Violators may intentionally use bypass routes when available to avoid being caught. In this study, the researchers worked with MSP to identify potential bypass routes for each of the existing fixed weigh stations. Figure 4.19 shows an example map of bypass routes for Monroe and Telegraph fixed weigh stations. Maps for all other fixed weigh stations are included in Appendix 4.3.

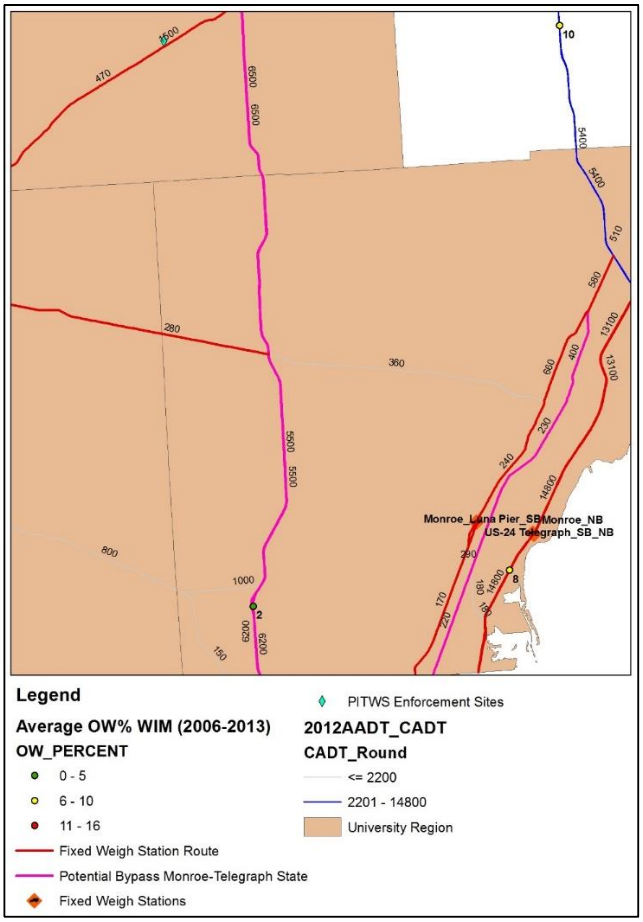


Figure 4.19 Potential bypass routes for Monroe and Telegraph fixed weigh stations

Table 4-10 presents a list of all potential bypass routes for each fixed weigh station together with details of the route, including commercial vehicle traffic, presence of PITWS or WIM.

Table 4-10 Potential bypass routes for Michigan fixed weigh stations

FWS	POTENTIAL BYPASS ROUTE	Average CADT	# of PITWS in the route	WIM PRESENT?	WIM overweight%	STATION ID	WIM USE
Monroe I-75 NB	US-23	5850	0	YES	2	8729	WIM
	M125	247	0	NO	-	-	
	US-24	240	0	NO	-	-	
Monroe I-75 SB	US-23	5850	0	YES	2	8729	WIM
	M125	247	0	NO	-	-	
	US-24	240	0	NO	-	-	
Grass Lake EB	M106	160	0	NO	-	-	
	US127 TO M50	864	0	YES	10	8029	WIM
	US127 TO US223	1197	2	YES	12	7049	WIM
Grass Lake WB	M52/M106	310	0	NO	-	-	
Cambridge	US-223	1197	2	YES	12	7049	WIM
	US12-US23	740	3	YES	9	8129	WIM
	Brooklyn Hwy/M-50/M-124	50	0	NO	-	-	
Telegraph US-24	US-23	5850	0	YES	2	8729	WIM
	M125	247	0	NO	-	-	
Powers	M35	175	2	YES	14	2229	WIM
	M69	130	2	YES	13	1199	WIM
Ionia EB	M50	345	0	NO	-	-	
	M50/M43	383	0	NO	-	-	
	I94-I69-I96	5533	0	YES	7	8869	WIM
	M21	190	0	NO	-	-	
Ionia WB	M50	345	0	NO	-	-	
	I94-I69-I96	5533	0	YES	7	8869	WIM
	M50/M43	383	0	NO	-	-	
	M21	190	0	NO	-	-	
New Buffalo EB	M239 and US12	465	1	YES	7	7139	CLASSIFICATION
New Buffalo WB	M239 and US12	465	1	YES	7	7139	CLASSIFICATION
Coldwater NB	North to US-12, East to I-69	720	2	YES	9	8129	WIM

Table 4-10 (contd.). Potential bypass routes for Michigan fixed weigh stations

FWS	POTENTIAL BYPASS ROUTE	Average CADT	# of PITWS in the route	WIM PRESENT?	WIM-recorded overweight percent	STATION ID	WIM USE
Fowlerville EB	US-127 to I-69 to US-23/I-75	3533	0	YES	8	5019	WIM
	I-96 to M-52 to I-69 to US-23/I-75	3420	0	YES	7	6449	WIM
	I-96 to M-52 to Grand River Ave to S. Grand to I-96 to US-23	590	0	NO	-	-	
	I-96 M-52 to E Howell Rd to W Mason Rd to N Burkhart Rd to I-96	225	0	NO	-	-	
	I-96 to M-52 to M-36 to US-23	1405	0	YES	6	8239	WIM
	I-96 to M-52 to I-94 to US-23	2798	0	YES	6	8239	WIM
Fowlerville WB	US-23 to I-94 to M-52 to I-96	2798	0	YES	6	8239	WIM
	US-23 to M-36 to M-52 to I-96	1405	0	YES	6	8239	WIM
	US-23 to I-96 to S. Grand to Grand River to M-52 to I-96	590	0	NO	-	-	
Pontiac NB	I75 TO US24, US24 TO M59, M59 TO I75	2083	0	NO	-	-	
	US 24-M59	1192	0	NO	-	-	

5 ANALYSIS OF FACTORS ASSOCIATED WITH COST AND BENEFITS OF ENFORCEMENT STRATEGIES

5.1 Introduction

Operational details of each enforcement strategy have implication on costs and benefits of that strategy. Costs related to each commercial vehicle enforcement strategy can be broadly categorized into two types: operator costs and user/public costs. Operator costs can include costs such as capital (construction), operation, and maintenance costs. Both operator costs and user/public costs can be different for each strategy due to a number of factors. For operator costs, factors such as permanent structure(s) needed, number of staff needed, technology used, geographic location (e.g., state boundary) and coverage of weigh stations, accessibility of stations, overall percentage of truck traffic, percentage of overweight trucks, etc., are among the determinants of the cost. While fixed weigh stations require permanent structures, portable scales and mobile strategies may not require such permanent structures although permanent infrastructure such as pavement cutouts/notches may need to be provided to increase efficiency.

On the other hand, each enforcement strategy is associated with different factors necessary to determine user/public costs. For example, the amount of delay resulting from enforcement strategies are different. While a basic fixed weigh station requires all trucks, including those complying with the laws and regulations, to enter the station and undergo weighing and inspection process, a preclearance system (at the most advanced fixed weigh station) can prescreen vehicles and allow those complying with the law to bypass the station. This reduces queues at weigh stations, which in turn, reduces delays. Also, the queue of commercial vehicles may extend into travel lanes on the mainline, creating potential safety concerns not only to commercial vehicles, but also to the general traveling public.

5.2 Cost Factors

In this study, four cost components were identified: construction/installation/upgrade costs; operating costs; labor costs; and maintenance costs. The following sections discuss these components for each level of fixed weigh stations. Chapter 4 discussed the details of each level of fixed weigh stations. These costs were derived from the costs of each fixed weigh station provided by MDOT and from other similar projects.

The construction/installation costs of a new basic fixed weigh station (excluding the building) was determined according to the recent cost estimates made by MDOT for the Fowlerville weigh station. A total estimate of $2,306,905 was obtained as detailed in Table 5.1. Optional features such as camera ($921), MoveForward VMS ($21,904), and speed VMS ($4,056) can also be added to a basic fixed weigh station to facilitate operations. These are not included in the estimate shown in the table below.

Table 5-1 Cost components of construction/installation of a basic fixed weigh station

Basic FWS Components	**Cost**
Static Scale Pavement	$37,000
Ramps	$1,136,000
Additional Parking	$207,000
Pavement leading to Parking	$309,000
Lights, static scale, speakers, lights for inspections	$477,905
Maintaining Traffic	$10,000
Mobilization	$130,000
Total Cost	**$2,306,905**

For other fixed weigh station levels, costs were determined according to the extra technologies and features present on each level in addition to those present at a basic fixed weigh station. These distinguishing features include mainline WIM, low-speed WIM with bypass lane and preclearance systems. Table 5.2 presents a summary of the costs for each level of fixed weigh station.

Table 5-2 Construction/installation cost components by fixed weigh station levels

Installation/Construction Components	Basic	Intermediate	Advanced	Most Advanced
Construction of New Basic Fixed Weigh Station with Static Scale	$2,306,905	$2,306,905	$2,306,905	$2,306,905
Camera	$921	$921	$921	$921
MoveForward VMS	$21,904	$21,904	$21,904	$21,904
Speed VMS	$4,056	$4,056	$4,056	$4,056
Mainline WIM		$136,000	$136,000	$136,000
Low Speed WIM			$156,176	$156,176
Bypass Lane			$530,500	$530,500
Overheight Detector (OHD)			$110,000	$110,000
PrePass System				$60,347
Total Cost	$2,333,786	$2,469,786	$3,266,462	$3,326,809

For the advanced mobile screening strategy the construction/installation/upgrade cost was obtained by considering construction of permanent intermittent safe enforcement sites (PITWS) with pavement cut-out, the cost of the portable scales and the cost of the mainline wireless WIM to perform the mobile screening operation. Table 5.3 presents the costs for all components of the advanced mobile screening strategy. The annual operating cost was determined to be $24,542.

Table 5-3 Cost components for advanced mobile screening

Components	Cost
Enforcement Site with PITWS	$ 191,962
Wireless WIM	$ 153,088
Wireless components: Transmitter (each)	$ 3,212
Wireless components: Receiver (each)	$ 2,141
Unique Vehicle Identifier (image capturing) - freeze camera	$ 19,143
Laptop	$ 4,818
Docking Station	$ 1,071
Portable scale	$ 48,000
Installing basic electronic screening equipment (AVI)	$ 16,689
Total estimate	**$ 440,123**

The operating cost for fixed weigh stations was based on the consumables and utilities spent at the enforcement site as provided by MDOT. The operating cost for each level of fixed weigh station is listed in Table 5.4. The labor cost for fixed weight stations was based on the assumption that one police officer is working at the location with an hourly rate of $46.12 (which includes both salary and benefits) as provided by MSP. For the virtual weigh stations, one police officer was also assumed to work at the same hourly rate. The number of hours of operation was used to determine the total labor cost. The number of hours of operation was assumed to be the average of scheduled hours. This was due to a lack of exact operation hours for individual enforcement stations.

Annual maintenance cost is also listed in Table 5.4 for all levels of fixed weigh station facilities. Maintenance costs of fixed stations considered pavement maintenance, pavement markings and maintenance of the building structure and other components which were made available by MDOT.

Table 5-4 Summary of average annual operating and maintenance costs

Station Level	Annual Operating Cost	Annual Labor Cost*	Annual Maintenance Cost
Most Advanced	$31,655	$287,289	$38,000
Advanced	$22,651	$155,406	$37,800
Intermediate	$25,486	$143,894	$15,000
Basic	$9,094	$41,969	$11,000

**Annual labor cost is determined as $46.12 x (average daily working hours) x number of working days per year*

5.3 Analysis of Benefit and Disbenefit Factors

Benefit factors analyzed in this study included pavement savings associated with reduction in overweight commercial vehicles as a result of enforcement activities as well as safety benefits/disbenefits. Safety benefits are measured in a reduction in potential crashes involving defective commercial vehicles, while safety disbenefits result from the potential increase in crashes due to presence of enforcement facilities, especially the fixed weigh stations. Also, travel time incurred by commercial vehicles as a result of entering the enforcement sites was considered as a disbenefit. Figure 5.1 presents the flow chart for quantifying travel time and number of overweight trucks captured by each strategy. The queue length (Q) and ramp capacity (C) play an important role in determining operation of a fixed weigh station. The number of captured overweight trucks was further used in quantifying pavement cost saving.

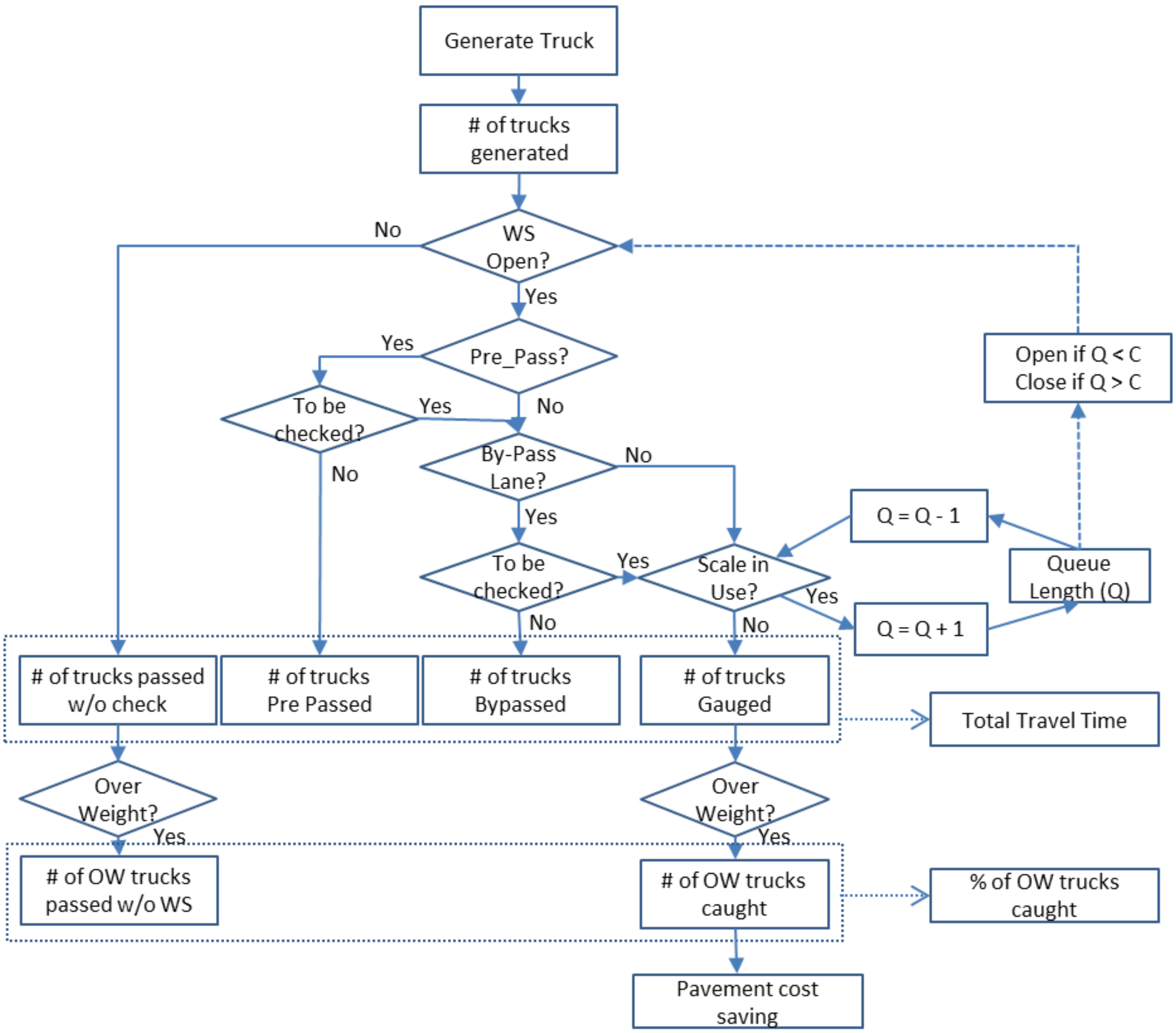


Figure 5.1 Quantification of travel time and number of overweight trucks captured by each strategy

5.3.1 Travel Time Saving Analysis

For travel time analysis, WIM data analysis results were used to obtain specific time-of day travel patterns of trucks and the percentage of overweight trucks. The two parameters were necessary to determine the number of trucks directed to the static scale, the bypass lane and or to the mainline depending on configuration and operation procedure of a given weigh station.

At a basic fixed weigh station, compliant trucks may experience unnecessary delays because they are required to enter the static scale. Technologies such as weigh in-motion sensors and bypass lanes can help improve and reduce the amount of trucks that are directed to the fixed scales while carrying legal loads. Also, pre-clearance systems reduce congestion at enforcement facilities by permitting compliant trucks to bypass the facility if not randomly selected for inspection. In this study, delay was determined as the difference between the ideal travel time when commercial vehicles travel through the mainline at their posted speed limit and the time commercial vehicles spend while traveling through the fixed weigh station ramp and/or the bypass lanes. Field observations at Grass Lake fixed weigh station determined that on average a truck takes about 1.42 minutes to be weighed. This time was added to the amount of time an average truck needs to go through static scale. Also, if a queue forms, there is additional delay caused by the queue.

With time-of-the-day pattern, percent overweight, the number of hours of operation, station layout and traffic volume, simulation was conducted to estimate the travel time added as a result of enforcement activities. The added travel time was considered as a disbenefit to the truckers. The trucker's travel time cost was estimated to be $31.22 per hour, consistent with other MDOT's estimations.

5.3.2 Pavement Saving Analysis

Pavement damage resulting from overweight trucks was estimated by computing the Equivalent Single Axle Loads (ESAL) imposed on roadways by these trucks. Pavements are designed to withstand a certain number of equivalent single axle loads (ESAL) during their service life. The structural behavior of flexible pavements is different from those of rigid pavements. Traffic loads can have a more severe effect in flexible pavements due to a lower flexural strength than rigid pavements. Therefore, pavement saving analysis considered both flexible and rigid pavement individually for the computations of equivalent single axle loads (ESAL). The ESAL was calculated based on WIM-recorded axle weights for single, tandem and tridem axles. ESAL equations are fourth-order functions. Therefore, as the axle weights increase, the damage to the roadway increases exponentially.

For the calculations of equivalent single axle load (ESAL) values, the following assumptions, consistent with AASHTO pavement design guidelines, were considered in this study: a Terminal Serviceability Index (TSI) =2.5 and a Pavement Structural Number (SN) =3.0 for flexible pavements. For rigid pavements, a slab depth (D) of 9 inches was assumed. For the assumptions stated above, the equivalent single axle load (ESAL) values were graphed according to the AASTHO Guide for the Design of Pavement Structures (1993). This was done for single, tandem and tridem axles and for each pavement type to obtain the load values needed to be assigned to each truck configuration observed in the WIM data analysis (for both legal and potential overweight trucks) according to the observed axle weights. Figure 5.2 presents a sample graph for single axle load for flexible pavement while the rest of the graphs are presented in Appendix 5.1.

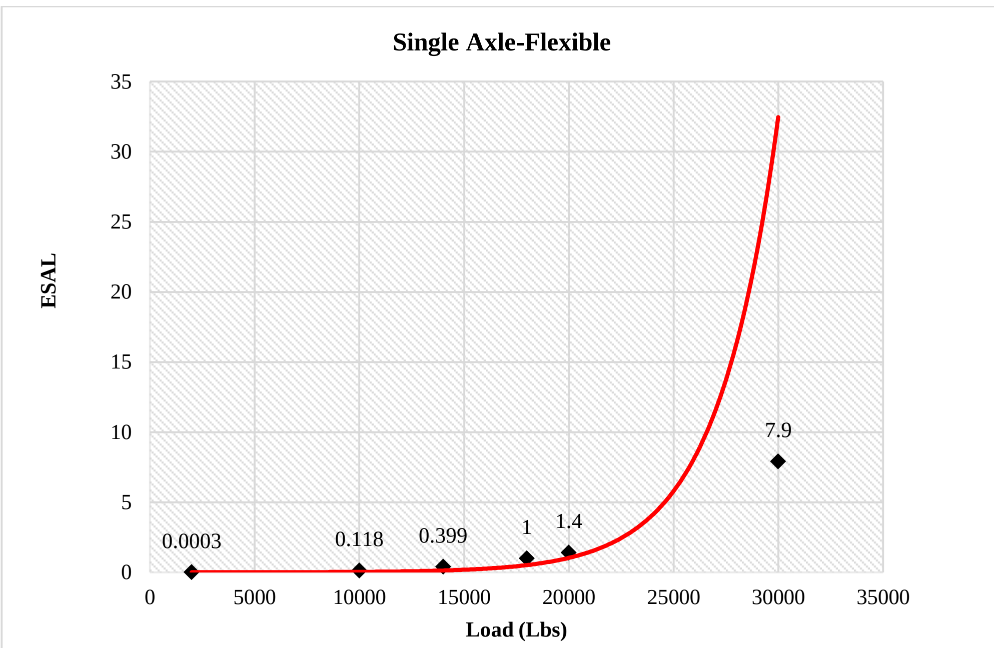


Figure 5.2 Single Axle Flexible Pavement ESAL

Subsequently, after plotting the equivalent single axle load (ESAL) graphs, the truck data obtained from WIM data analysis was used to determine the actual number of different truck configurations available for each truck group (by number of axles). This refers to the number of possible configurations a specific truck group can have, based on spacing of their axles. For example, three-axle trucks can have two distinct axle configurations: (1) one single axle plus one tandem axle (1S+1T), (2) three single axles (1S+1S+1S). The impact of each axle on the pavement varies due to the axle load distribution, which is affected by axle configuration. As a result, different ESAL values were obtained for sample commercial vehicles in each configuration.

To account for the numbers of commercial vehicles for each configuration, proportions of the cases available were extracted from the WIM data and the weighted average was computed to estimate a unique ESAL value for each truck group. This procedure was performed for the trucks traveling under normal loading and for the trucks with excess load or considered to be overweight. Table 5-5 shows the weighted unit loading for each type of trucks (by number of axles) for legally loaded trucks for flexible pavement. Appendix 5.2 presents the unit loading for overweight trucks (flexible pavement), and normal and overweight trucks (for rigid pavement).

Table 5-5 Unit loading for flexible pavement

No. of Axles	Truck Configuration	ESAL	Proportions	Weighted Average ESAL
2 Axles	1S+1S	2	1	2
3 Axles	1S+1T	1.54	0.9	1.686
	1S+1S+1S	3	0.1	
4 Axles	1S+1S+1T	2.32	0.9	2.369
	1S+1T+1S	2.81	0.1	
5 Axles	1S+1T+1T	2.08	0.8	2.445
	1S+1T+1S+1S	3.54	0.15	
	1S+1S+1S+1S+1S	5	0.05	
6 Axles	1S+1T+1T+1S	1.86	0.2	3.1115
	1S+1T+1S+1S+1S	4.54	0.45	
	1S+1T+1TR	1.99	0.35	
7 Axles	1S+1T+2T	2.45	0.9	2.5905
	1S+1T+1S+1S+1S+1S	5.81	0.05	
	1S+1TR+1TR	1.9	0.05	
8 Axles	1S+1T+1S+1TR+1S	4.26	0.65	3.9765
	1+1T+1S+2T	3.45	0.35	
9 Axles	1S+1T+1S+2T+1S	4.18	0.7	4.4515
	1S+1T+1S+1T+1TR	3.31	0.05	
	1S+1T+1S+1TR+1S+1S	5.44	0.25	
10 Axles	1S+1T+1S+1TR+1TR	3.71	0.7	3.971
	1S+1T+1T+TR+1S+1S	4.58	0.3	
11 Axles	1S+1T+1S+2T+1TR	3.63	0.5	3.477
	1S+1T+4T	2.82	0.35	
	1S+1T+1S+2T+1S+1T	4.5	0.15	
S= Single Axle; T= Tandem Axle; TR= Tridem Axle				

Besides traffic loading, pavement life is affected by climate conditions (freezing and thawing, etc.). Estimating the proportions of damage by loading and climate conditions is a challenge. However, previous studies have shown that load and non-load pavement damage shares could range from 25/75 to 85/15 [Liz and Sinha (2000); Ahmed et al (2013); Podborochynski et al (2011)]. In this study, a load share of 50/50 was assumed, where 50 percent represents the damage attributed to climatic conditions and the other 50 percent damage is attributed to loading resulting from commercial vehicles. A portion of damage associated with excess load was estimated as described below.

To quantify pavement damage by overweight trucks, the truck percentages for each truck type (by number of axles) out of the total trucks undergoing weight inspection was determined. This information was a result of WIM data analysis, which was used to determine overweight trucks at a given enforcement site. Then, with the overweight distribution by location or region, the same procedure was done to determine the total number of overweight trucks potentially captured for each axle group. It should be noted that there was no actual data on the number of captured trucks by number of axles. Therefore, the number of potentially captured overweight trucks was determined by simulating the operation of each enforcement site to isolate the potential number of overweight trucks (based on the observed overweight percent from WIM data) checked by the officer. With the equivalent single axle load (ESAL) values for normal loading and overweight loading, the excess unit load was computed as the difference between the two (ESAL) values. Using the total number of potentially captured overweight trucks, an estimate of the total ESAL resulting from overloading was obtained.

Pavement saving was finally quantified based on dollar per lane-mile ($/lane-mile) obtained from MDOT and distributed 50-50 between loading and climate conditions as stated above. The unit cost per ESAL per lane-mile ($/ESAL/lane-mile) was determined as follows:

- The average annual maintenance cost (per lane-mile) of $6,200 was obtained by averaging the maintenance costs presented in MDOT pavement design manual and assuming only 50 percent is attributed to loading. The annual cost was obtained from the total maintenance cost given in the manual and the number of years the life of the pavement was extended.
- Average commercial vehicle average daily traffic (CADT) of 980 was obtained by averaging CADT values across all Michigan state roads. Assuming a 50-50 directional distribution and 30-70 lane distribution for a four lane roadway, the average daily commercial vehicle volume per lane was determined to be approximately 343 trucks.

- Using the average distribution of trucks by number of axles and configurations in the state of Michigan, it was determined that approximately 240,300 ESAL would be applied to one mile of the roadway in one year as a result of this traffic.
- Assuming that the average maintenance cost associated with loading is a result of the above ESAL, the unit cost per ESAL per lane mile was determined as ($6,200/240,300) = $0.03/ESAL/lane-mile).

To understand the impact of damage share proportions (loading vs climate), a sensitivity analysis on the cost ($/ESAL/lane-mile) was conducted. As it can be seen in Figure 5.3, pavement maintenance cost is sensitive to damage share proportions. As a result, this study assumed a 50-50 damage share.

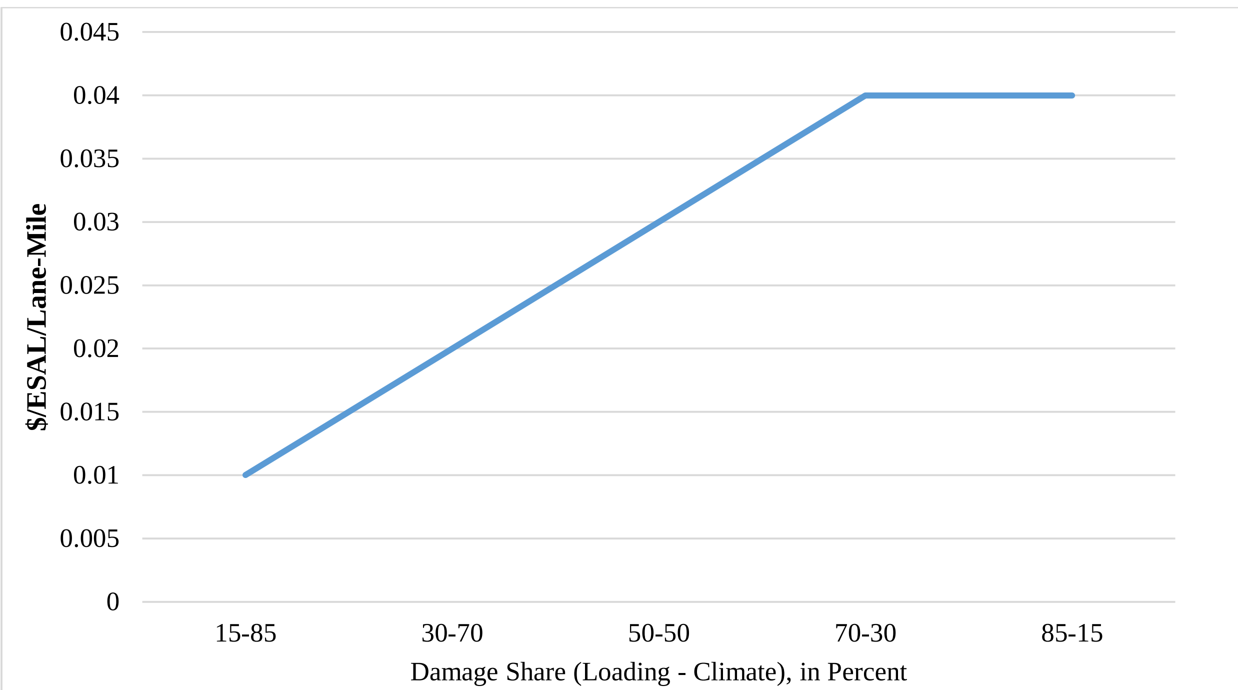


Figure 5.3 The impact of damage share proportions on unit pavement maintenance cost

Trip length (in lane-miles) was computed under the assumption that once an overloaded commercial motor vehicles passes a point, it will damage pavement according to the loading established above for the roadway length equal to the distance from that point to the next weight enforcement location where the truck is captured. Under this assumption, the pavement length saved by a truck captured at a given weight enforcement location was taken to be the average distance from that location to all other enforcement points along the possible routes available to the truck. With potential pavement length saved by catching an overloaded truck, the number of potentially captured trucks, and the estimate of the saved ESAL, the total pavement savings were determined using the unit cost. As shown, this pavement saving is sensitive to the number of overloaded trucks captured as well as potential distance of pavement that would have been damaged if the truck was not captured. The number of overloaded trucks captured is a function of many factors including efficiency of a given enforcement site (location), truck volume and weight violation rate.

5.3.3 Safety Analysis

Safety analyses consisted of three major components: crashes involving defective commercial vehicles, crashes that occurred at the fixed weigh station, and those that happened before the facility (due to diverging and merging into the station). Safety analyses were aimed at identifying the impact of the presence of fixed weigh stations on traffic operations, and also the impact of truck inspections on safety downstream of weigh stations. Diverging and merging of commercial vehicles (CMVs) as a result of the presence of fixed weigh station can create traffic conflicts. The analysis also focused on the impact of safety inspections conducted at fixed weigh stations on the frequency of crashes involving defective commercial vehicles downstream of the facility. It was anticipated that commercial vehicle enforcement at fixed weigh stations reduces the number of crashes involving defective commercial vehicles downstream of the station. Reduction in crashes involving defective commercial vehicles can be considered a saving resulting from presence of enforcement upstream. The following sub-sections summarize the details of safety analysis.

Identifying Influential Segments at Fixed Weigh Stations

In order to identify influential locations in the proximity of fixed weigh stations, the research team categorized the influential segments into three major sections: before the facility, at the facility, and after the facility (see Figure 5.4). The influential segment "before the facility" was the distance from the location of the weigh station advanced sign where most likely truckers begin to execute maneuvers to enter the weigh station if it is open. The 2011 Michigan Manual on Uniform Traffic Control Devices indicates that the first weigh station and rest area signs, which are advance warning signs, should be located 1 mile (5,280-ft) from the painted nose of exit ramp. Before the fixed weigh station, the second sign which requires qualified trucks (by weight) to enter the weigh station should be located 4,000-ft from the painted nose of exit ramp, and the third sign which is the exit direction sign should be located before at least 800-ft from the painted nose of exit ramp. Due to excessive length of influential segments before facility and in order to study the crash pattern in that segments, two incremental distances of 5,280-ft to 3,000-ft and 3,000-ft to 0-ft from the exit gore of the facility, were used. It is also important to mention that truck drivers may react to the sign as soon as they see it, which could be a few feet before the first sign. In this study, however, the analysis focused on crashes occurring from the location of the first sign. With regards to the designated distance of the influential segments "after facility" which represents the merging area, Janson et al. (1998) indicated that the influential segments of merging ramps are 0.15 miles (792-ft) plus acceleration distance of merging ramps. Since the average acceleration distance of merging ramps for the twelve freeway weigh stations was 0.22 miles (1,160-ft), the adopted distance of the influential segment after facility was 1,950-ft from the painted nose of the freeway entrance ramp as shown in Figure 5.4. While the "before the facility" and "after the facility" segments were simply specific distances before the exit ramp and after the entry ramp of the weigh station, respectively, the "at the facility" segment was defined as the segment between the gores of the exit and entrance ramps of the freeway.

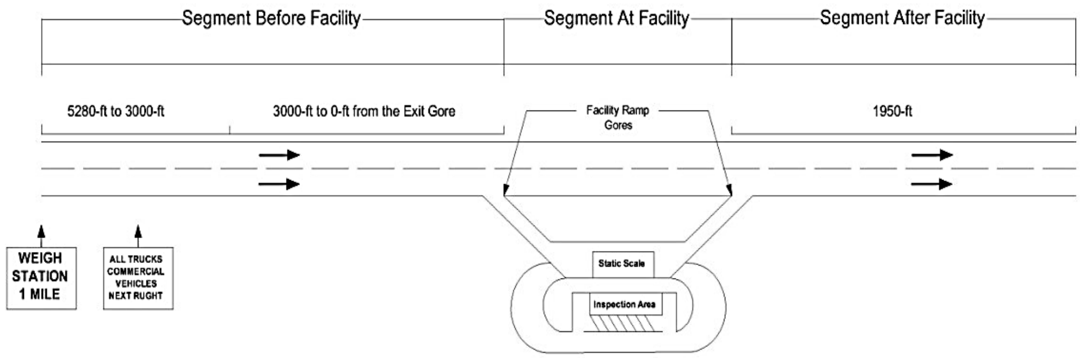


Figure 5.4 Influential segments at fixed weigh stations

Eight years of crash data (2004-2011) was collected from fixed weigh station segments as well as rest areas with Permanent Intermittent Truck Weigh Stations (PITWS) and regular rest areas. Also, crashes were collected from comparison segments, which were carefully selected along sites with traffic and geometric characteristics similar to these segments. After eliminating crashes involving deer, a total of 6,954 crashes were used for analyses. These included 3,670 crashes that occurred in the influential segments (ISs) of fixed weigh stations (674) and rest areas (2,996); and 3,284 crashes that occurred in the comparison segments (CSs). Figure 5.5 presents the percentages of crashes by severity for fixed weigh stations, rest areas and comparison sites for severe crashes. Analysis showed that Michigan freeway segments in the vicinity of weigh stations are associated with relatively more severe and a higher frequency of crashes compared to rest areas and comparison sites. Comparison sites were freeway segments with characteristics similar to those of the influential segments, but without any facility.

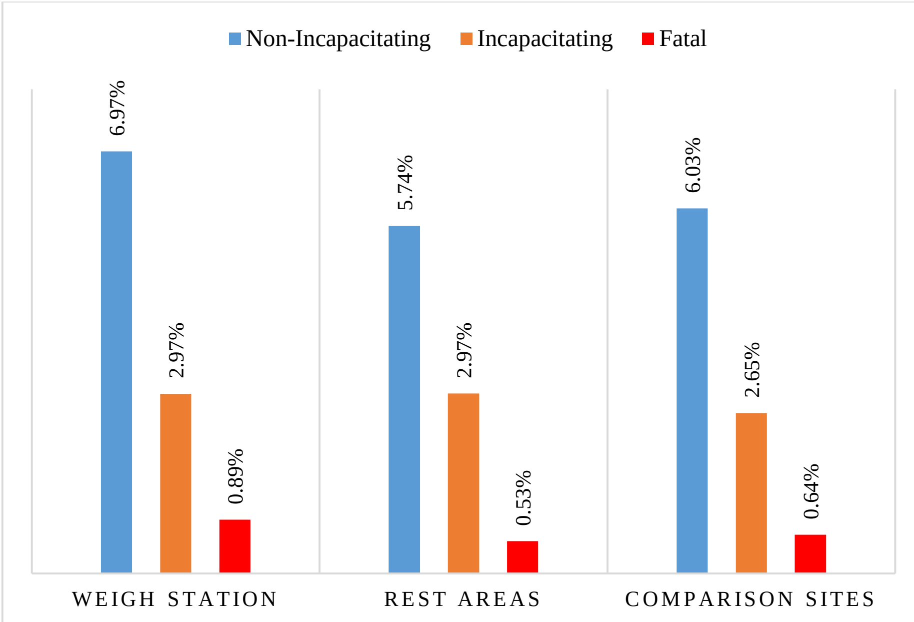


Figure 5.5 Distribution of crash severity

In order to discern if the presence of facilities such as fixed weigh stations and rest areas impact the number of crashes observed, statistical modeling was performed. When modeling crash counts, Poisson regression analysis or Negative Binomial (NB) regression analysis can be used (Yaacob et al, 2011; Zlatoper, 1989; Lord, 2006; Chin and Quddus, 2003; Miaou and Lum, 1993; and Noland and Quddus, 2004). The choice between the two model types depends on the relationship between the mean and the variance of the data. If the mean is equal to the variance, the data is assumed to follow a Poisson distribution, and hence the Poisson regression analysis can be performed. However, as a result of possible positive correlation between observed accident frequencies, overdispersion may occur (Hilbe, 2011). Accident frequency observations are said to be overdispersed if their variance is greater than their mean. If overdispersion is detected in the data, NB regression analysis should be used. Standard textbooks (for example Hilbe 2011; Greene 2012; and Washington et al 2011) present clear derivation of the Poisson, and Negative Binomial (NB) models. According to the Poisson distribution, the probability $P(y_i)$ of intersection *i* having y_i crashes in a given time period (usually one year) can be written as:

$$P(y_i) = \frac{EXP(-\lambda) \cdot \lambda_i^{y_i}}{y_i!} \tag{1}$$

where λ_i denotes the Poisson parameter for intersection *i*. By definition, λ_i is equal to the expected number of crashes in a given time period for intersection *i*, $E[y_i]$. According to Washington et al. (2011), the expected number of crash occurrences λ_i, can be related to a vector of explanatory variables, $\boldsymbol{X}_i$ as follows:

$$\lambda_i = EXP(\boldsymbol{\beta X}_i) \tag{2}$$

where $\boldsymbol{\beta}$ represents a vector of estimable parameters. Under the Poisson assumption, the mean and variance of crashes occurring at an intersection in a year are equal (i.e. $E[y_i] = Var[y_i]$). With *N* observations, the parameters of the Poisson model can be estimated by maximum likelihood method with a function which can be shown to be as follows:

$$LL(\beta) = \sum_{i=1}^{N} [-EXP(\boldsymbol{\beta X}_i) + y_i \boldsymbol{\beta X}_i - \ln(y_i!)] \tag{3}$$

The Poisson assumption of equal mean and variance of the observed crash occurrences is not always true. To handle the cases where the mean and variance of crashes are not equal, the Poisson model is generalized by introducing an individual, unobserved effect, ε_i, in the function relating crash occurrences and explanatory variables as follows:

$$\lambda_i = EXP(\boldsymbol{\beta X}_i + \varepsilon_i) \tag{4}$$

in which $EXP(\varepsilon_i)$ is a gamma-distributed error term with mean one and variance α^2. With such a modification, the mean λ_i becomes a variable that follows binomial distribution. The mean-variance relationship becomes:

$$Var[y_i] = E(y_i) \cdot [1 + \alpha E(y_i)] = E[y_i] + \alpha E(y_i)^2 \tag{5}$$

If α is equal to zero, the negative binomial distribution reduces to Poisson distribution. If α is significantly different from zero, the crash data are said to be overdispersed (positive value) or underdispersed (negative value). As stated earlier, overdispersion is a result of possible positive correlation between observed accident frequencies. When α is significantly different from zero, the resulting negative binomial probability distribution is:

$$P(y_i) = \frac{\Gamma\left(\left(1/\alpha\right) + y_i\right)}{\Gamma\left(1/\alpha\right) y_i!} \left(\frac{1/\alpha}{\left(1/\alpha\right) + \lambda_i}\right)^{1/\alpha} \left(\frac{\lambda_i}{\left(1/\alpha\right) + \lambda_i}\right)^{y_i} \tag{6}$$

where $\Gamma(x)$ is a value of the gamma function, y_i is the number of crashes for intersection i and α is an overdispersion parameter.

Crashes "Before the Facility"

A number of traffic and roadway characteristic factors were collected from both influential segments (segments before fixed weigh stations and rest areas) and comparison segments. Using the Negative Binomial regression, models of crash frequency that occurred in the "before the facility" influential segments were estimated separately. It was determined that the presence of a fixed weigh station did not have a significant influence on crashes occurring in the 3,000-ft to 0-ft segment. However, crashes occurring in the (5,280-ft to 3,000-ft) were significantly impacted by presence of fixed weigh station. Table 5-6 presents the significant variables for the model representing crashes in the (5,280-ft to 3,000-ft) segment "before the facility." In addition to the presence of a fixed weigh station, it can be seen that crashes in this segment are associated with median guardrail, commercial vehicle annual daily traffic (CADT), number of lanes, and the pavement condition. Negative coefficients signify a reduction of crashes in association with the variable, while positive coefficients indicate a potential increase in crashes with respect to the variable.

Table 5-6 Negative Binomial Model estimation results for "Before the Facility"

Variable	Coefficient	z-value	p-value
Presence of Weigh Station	0.566	2.03	0.042
Guardrail Median	-1.932	-3.98	0.000
CADT	0.0003	4.51	0.000
Number of Lanes	0.463	2.81	0.005
Excellent/Good pavement	-0.209	-1.31	0.190
Constant	0.685	1.91	0.056

Number of Observations: 154
Log Likelihood: -500.48
LR chi2(7): 47.46
Prob > chi2: 0.0000
Pseudo R2: 0.0453

From the estimated parameters above, the final equation of expected number of crashes in this specific influential segment can be given as follows:

$$N = exp[0.685 + (0.566)(WS) - (1.932)(GM) + (0.0003)(CADT) + (0.463)(NL) - (0.209)(PC)] \quad (7)$$

Where:

N = the expected number of crashes occurred in the conflict area.

WS = Presence of weigh station (dummy variable).

GM = guardrail median type (dummy variable).

CADT = commercial average daily traffic (continuous variable).

NL = number of lanes (continuous variable).

PC = pavement condition

In order to quantify the magnitude of the effect of the presence of a weigh station in the traffic stream, a crash modification factor (CMF) associated with presence of fixed weigh station (N_{WS}) can be computed as follows:

$$N_{WS} = EXP(\beta * WS) = EXP(0.566*1) = 1.76 \quad (8)$$

This indicates that presence of fixed weigh stations in freeway increases the likelihood of crash occurrence in the (5,280-ft to 3,000-ft) influential segment "before the facility" by 76 percent.

Crashes "At the Facility"

Table 5-7 presents the estimation results of crash frequency in the influential segments "at the facility." The results of the estimation indicates that variables such as the presence of a weigh station, presence of a rest area, guardrail median type, CADT, number of lanes, pavement conditions, width of median, and width of the right of way were found to be significant in the model of influential segments at the facility. The negative coefficient of the presence of a weigh station in freeways indicates that crash frequency will likely decrease between the exit and entrance gores of weigh station facilities. This can be attributed to the fact when the fixed weigh station is open, all or a significant number of trucks will be traveling through the fixed weigh station, and not the "at facility" segment except at fixed weigh stations with preclearance systems. Also, activities at the fixed weigh station may increase other drivers' alertness and therefore minimize the likelihood of a crash in this area.

Table 5-7 Negative Binomial Model results for "At the Facility"

Variable	Coefficient	z-value	p-value
Presence of Weigh Station	-0.305	-2.12	0.034
Presence of Rest Area	0.210	1.79	0.073
Guardrail Median	-0.709	-1.85	0.065
AADT of CMV	0.0003	5.14	0.000
Number of Lanes	0.376	2.85	0.004
Excellent/good pavement	-0.283	-2.24	0.025
Width of the Median	-0.004	-2.51	0.012
Right of Way Width	0.002	1.85	0.065
Constant	0.783	1.76	0.079
Number of Observations: 154 Log Likelihood: -524.29 LR chi2(7): 83.47 Prob > chi2: 0.0000 Pseudo R2: 0.0737			

To quantify the effect of presence of weigh station in traffic stream, a crash modification factor (CMF) associated with presence of fixed weigh station (N_{WS}) can be computed as follows:

$$N_{WS} = EXP(\beta * WS) = EXP(-0.305*1) = 0.74 \quad (9)$$

The results indicated that the presence of a fixed weigh stations may likely decrease the likelihood of crash occurrence in this particular influential segment ("at the facility") by 26 percent.

Crashes "After the Facility"

The estimation results in Table 5-8 reveal that concrete barrier median type, graded with ditch median type, CADT, number of lanes, and width of median were found to be significant at the 80 percent confidence level. The insignificant coefficients of the presence of a weigh station and presence of a rest area indicate that crashes that occurred after the facility (within 1950-ft from the entrance gore) are unlikely to be significantly influenced by presence of the weigh station.

Table 5-8 Negative Binomial Model results for "After the Facility"

Variable	Coefficient	z-value	p-value
Presence of Weigh Station	-0.305	-0.96	0.335
Presence of Rest Area	0.052	0.33	0.743
Ditch Grade Median	0.966	1.68	0.092
Concrete Barrier Median	0.854	1.39	0.163
CADT	0.0001	1.52	0.128
Number of Lanes	0.550	2.95	0.003
Right of Way Width	-0.002	-1.63	0.103
Constant	0.111	0.11	0.914
Number of Observations	154		
Log likelihood	-445.37251		
LR chi2(7)	28.25		
Prob > chi2	0.0002		
Pseudo R2	0.0307		

Crashes Involving Defective Commercial Vehicle

To conduct a safety analysis for crashes that involved defective commercial vehicles, a model was developed using the negative binomial regression. It used crashes downstream of the fixed weigh stations and comparison segments with similar characteristics. These segments downstream of the fixed weigh stations were relatively longer segments compared to those selected in the analyses of all crashes described above. This was because while the analysis of all crashes focused on crashes caused by the immediate impact of the presence of fixed weigh stations resulting from the merging of trucks, the analysis of defective commercial vehicle crashes focused on the impact of removing such defective trucks from the traffic stream. This impact can be realized over relatively longer distances over which these trucks travel downstream. However, ensuring that no new defective trucks from other intersecting roadways in the segments was critical. To that end, the segments considered were between the fixed weigh station and the nearest major interchange (intersection) downstream of the fixed weigh station. Table 5-9 presents the significant variables determined to be associated with the occurrence of crashes involving defective commercial vehicles downstream of the fixed weigh stations. The model indicates that the presence of fixed weigh stations is significantly associated with reduction of crashes involving defective commercial vehicles downstream of the station at the 90 percent level of confidence. Other influential variables included the segment length, and the number of lanes of the segment.

Table 5-9 Negative Binomial Model results for defective commercial vehicle crashes

Variable	Coefficient	z-value	p-value
Presence of Enforcement	-1.091	-1.84	0.065
Segment Length	0.018	1.67	0.096
Number of Lanes	0.377	0.70	0.485
Constant	-1.402	-1.04	0.299
Number of Observations	30		
Log Likelihood	-24.59		
LR chi2(7)	5.77		
Prob > chi2	0.1231		
Pseudo R2	0.1051		

From the estimated parameters above, the final equation of expected number of crashes was computed and it is given as follows:

$$ND = exp\ [(-1.091401)\ (PE) + (0.0182083)\ (SL) + (0.3770776)\ (NL) - 1.401856] \qquad (10)$$

where:

ND = the expected number of crashes involving defective commercial motor vehicles.

PE = Presence of weigh station (dummy variable).

SL= Segment Length.

NL = number of lanes.

Subsequently, the crash modification factor was computed as:

$$CMF - EXP(\beta * PE) = EXP(-1.09 * 1) = 0.34 \quad (11)$$

The result indicates that the presence of enforcement decreases the likelihood of crashes involving defective commercial vehicle by 66 percent.

Determining the Net Safety Impact of Fixed Weigh Stations

To determine the net safety impact of fixed weigh stations in the influential segment "before facility", the segment "at the facility" and the segment downstream of the fixed weigh stations were considered. These were the only locations whose safety was determined to be influenced by the presence of fixed weigh stations. It should be noted that the analyses presented above found that the segment "before the facility" exhibited an increase in the likelihood of crash occurrence while the segment "at the facility" showed a decrease in the likelihood of crash occurrence as a result of the presence of fixed weigh station. Furthermore, the segment downstream of the fixed weigh stations were shown to have a reduction in the number of crashes involving defective commercial vehicles as a result of the presence of a fixed weigh station. The actual number of crashes at all these segments resulting from their respective impacts was computed for all fixed stations. Then the annual average of these crashes was obtained for each enforcement location. It is worth noting here that the reduction of crashes downstream the segment can be realized over a long distance and therefore may always be underestimated. Defective trucks that pass an enforcement site undetected may travel longer distances before being involved in a crash. Table

5-10 shows the net average crashes per year for freeway fixed weigh stations while Appendix 5.3 shows the detailed computations of the net safety impact. Adjustments of number of crashes were made to reflect the proportion of time when the fixed weigh stations are in operation. Overall, the average net crashes per year was determined to be less than one crash. Considering the possibility of underestimating crash reduction downstream of the fixed weigh station, the net safety impact of presence of enforcement facilities was considered to be very minimal.

Table 5-10 Net safety impact of freeway fixed weigh stations

Level	Weigh Station	Net Average Crashes/Year
Most Advanced	Monroe_NB	+3
	New Buffalo_EB	+1
Advanced	Grass Lake_EB	+1
	Grass Lake_WB	0
	Coldwater_NB	0
	Monroe_SB	0
	New Buffalo_WB	+1
Intermediate	Fowlerville_EB	+1
	Fowlerville_WB	+1
	Ionia_EB	0
	Ionia_WB	0
Basic	Pontiac_SB	0
Overall Average		**+0.67**

6 BENEFIT-COST ANALYSIS OF ENFORCEMENT STRATEGIES

6.1 Introduction

To conduct a benefit-cost analysis, specific data on cost and benefit components discussed in Chapter 5 were derived for each alternative strategy. The cost components included construction/installation/upgrade costs, operating costs, labor costs, and maintenance costs. Additional travel time for commercial vehicles entering a fixed weigh station (including the use of bypass lane triggered by the low-speed WIM) was also considered. The benefit components considered were mainly pavement cost saving associated with commercial vehicle enforcement.

The conventional benefit-cost ratio (BCR) approach was adopted in determining economic worthiness of each strategy. A BCR is the ratio of present worth (PW) of benefits to present worth (PW) of costs. All disbenefits were treated as negative benefits. Future values were discounted to reflect its current value. A 30 year real discount rate of 1.9% obtained from the Federal Office of Management and Budget Circular A-94 (http://www.whitehouse.gov/omb/circulars_default) was applied to the life cycle cost (LCC) analysis. A BCR greater than one indicates that the strategy is economically beneficial while a BCR less than one indicates that the strategy is not. On the other hand, a negative BCR signifies that the disbenefits outweighs the benefits. It shows that the station generates more delays enough to outweigh the benefits. The following section documents the results of the benefit-cost analysis of each strategy. Appendix 6.1 presents a full sample computation of BCR.

6.2 Benefit-Cost Analysis Results

6.2.1 Existing Fixed Weigh Stations

This analysis focused on the existing fixed weigh stations and quantified their costs and benefits to determine individual BCR as well as the overall BCR. Table 6.1 presents the benefit-cost analysis results for all 15 fixed weigh stations. The present worth values for costs, benefits and disbenefits are shown in Appendix 6.2.

Table 6-1 Benefit-cost analysis results for individual fixed weigh stations

Fixed Weigh Station	Highway	Level	BCR
New Buffalo_EB	I-94 EB	Most Advanced	12.77
Monroe_NB	I-75 NB	Most Advanced	8.86
New Buffalo_WB	I-94 WB	Advanced	10.09
Monroe_SB	I-75 SB	Advanced	8.91
Grass Lake_EB	I-94 EB	Advanced	4.00
Grass Lake_WB	I-94 WB	Advanced	4.11
Coldwater_NB	I-69 NB	Advanced	1.94
Ionia_WB	I-96 WB	Intermediate	-0.84
Ionia_EB	I-96 EB	Intermediate	-0.84
Fowlerville_EB	I-96 EB	Intermediate	-0.30
Fowlerville_WB	I-96 WB	Intermediate	-0.30
Powers	US-41 & US-2	Basic	1.48
Pontiac_SB	I-75 SB	Basic	-0.31
Telegraph	US-24 NB & SB	Basic	0.00
Cambridge	M-50 & US-12	Basic	0.33
		OVERALL	**4.59**

Examining the results in Table 6.1, it can be seen that advanced and most advanced fixed weigh stations are more economically beneficial compared to other levels. The most advanced fixed weigh stations utilize pre-clearance systems (i.e. PrePass) in addition to a bypass lane (which utilizes low-speed WIM) to reduce the number of commercial vehicles required to enter the static scale and hence saving a great deal of travel time to truckers. They also increase efficiency of enforcement officers by allowing them to focus on potential violators only while allowing potentially compliant commercial vehicles to bypass the station. However, travel speed in the bypass lane is low compared to the mainline and hence the overall travel time saving of advanced fixed weigh stations is less than that of the most advanced.

On the other hand, intermediate fixed weigh stations at Fowlerville and Ionia may be generating greater disbenefits due to their inability to handle the truck volume present with their current configuration which requires all trucks to enter the fixed weigh station. Also, the amount of time these fixed weigh stations are open could have an implication on their benefits. To that end, analysis on the impact of operating time on benefits of these fixed weigh stations was conducted. Figure 6.1 shows that increasing number of open hours while maintaining their current level (configuration) would not improve their BCR to acceptable levels. Current scheduled hours are shown in the circle.

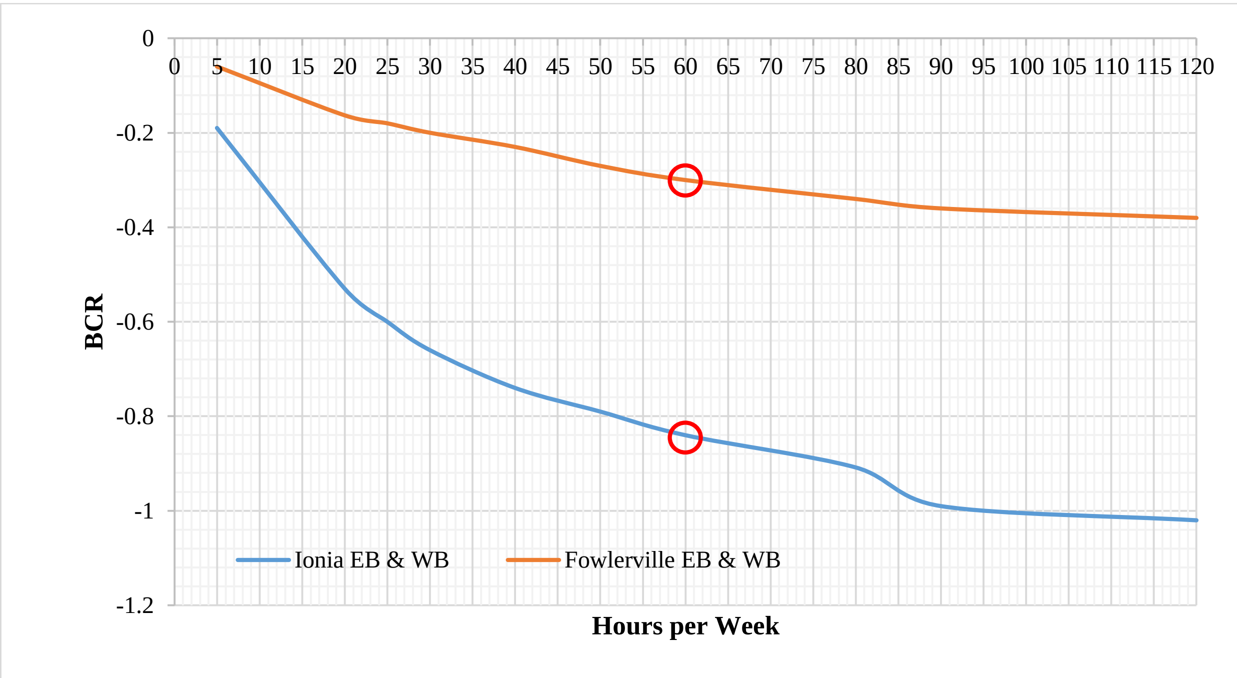


Figure 6.1 Impact of opening hours on BCR for Fowlerville and Ionia FWS

For basic fixed weigh stations, it can be observed that their BCRs are less than one (except Powers), signifying that they are not economically beneficial. Powers, the only fixed weigh station in the Upper Peninsula, is one of the most isolated fixed weigh stations such that an overweight truck caught at this station would have potentially travelled a longer stretch of highway before being caught, hence damaging more pavement.

Further analysis on the impact of operation hours on the BCR was conducted for Telegraph, Cambridge, Pontiac and Powers. Figure 6.2 presents the analysis results comparing BCR values at different levels of hours of operation. The results show that increasing the number of hours when the station is open would not improve the BCR values to acceptable levels for Telegraph, Cambridge and Pontiac. However, increasing hours at Pontiac to 60 per week is most likely to improve the BCR from the current 1.48 to 1.95. Increasing hours beyond 60 per week will lead to a decrease in the BCR. Table 6.2 summarizes the impact of operation hours on all fixed weigh stations in their existing conditions.

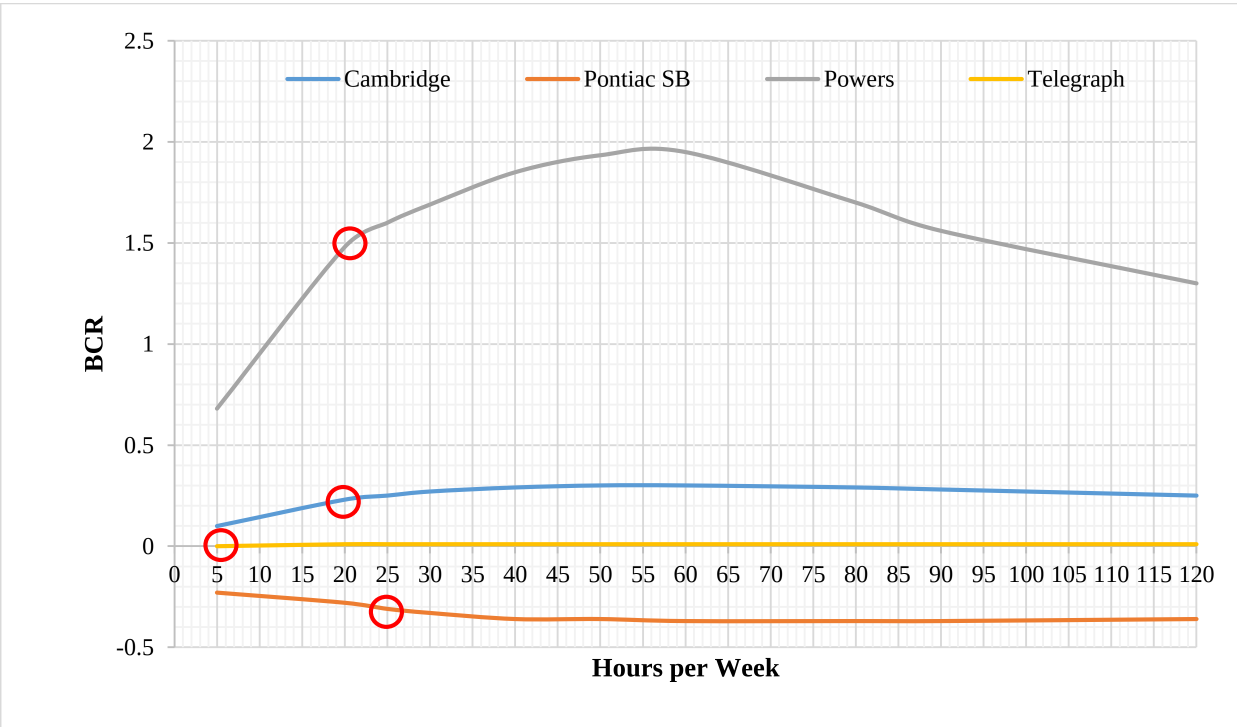


Figure 6.2 Impact of opening hours on BCR for basic fixed weigh stations

Similar analysis of the impact of operation time on the BCR was conducted for advanced and most advanced fixed weigh stations. Figure 6.3 presents the results for advanced level while Figure 6.4 shows the results for most advanced level. As it can be seen in Figure 6.3, New Buffalo WB fixed weigh station could use more hours to improve the BCR. However, it is important to understand that most of the pavement saving benefits realized at this fixed weigh station will be in the state of Indiana. Monroe SB, Grass Lake EB and Grass Lake WB are currently scheduled to operate optimally. For Coldwater fixed weigh station, increasing the hours of operation from 25 to 60 per week could improve the BCR from 1.94 to 2.90. Table 6.2 summarizes the impact of operation hours on all fixed weigh stations in their existing conditions.

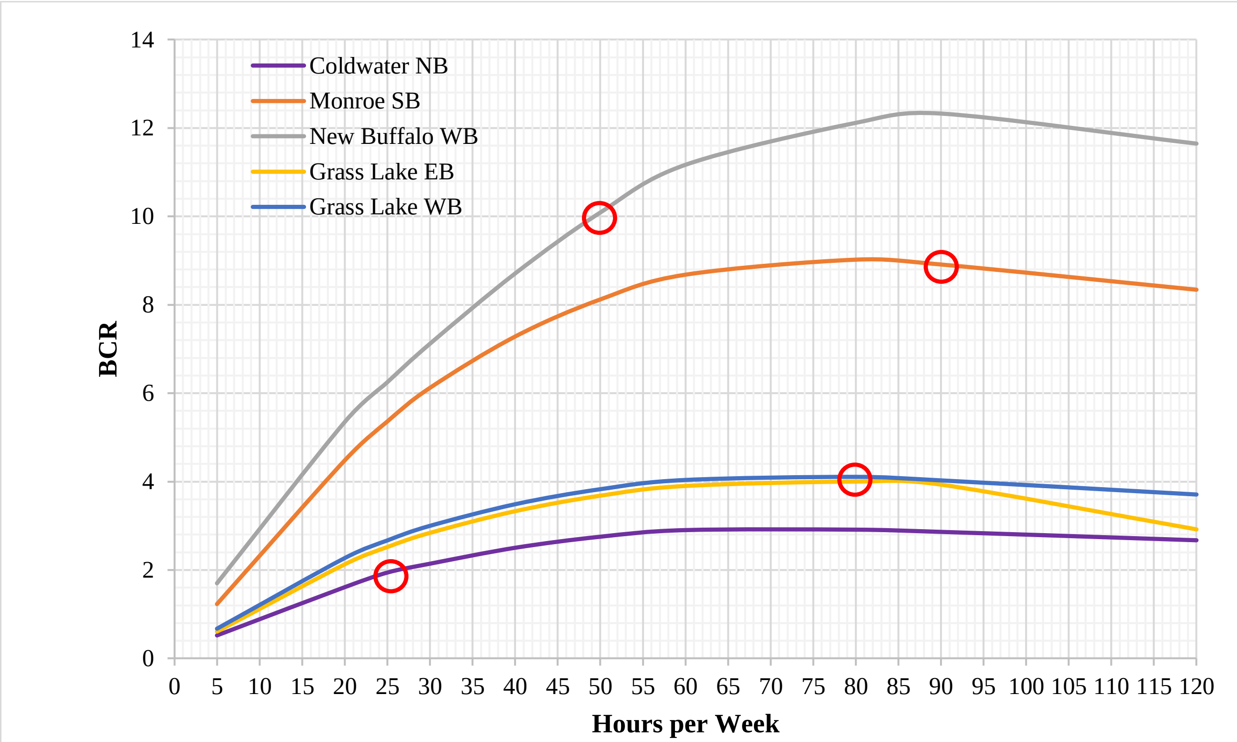


Figure 6.3 Impact of opening hours on BCR for advanced fixed weigh stations

Similarly, the results of most advanced fixed weigh stations (Figure 6.4) show that operating these two fixed weigh stations for 90 hours per week could result into slightly higher BCR. However the increase is not significant. It should be noted that longer hours of operation mean more labor cost. Table 6.2 summarizes the impact of operation hours on all fixed weigh stations in their existing conditions and identifies potential optimal operation hours (highlighted).

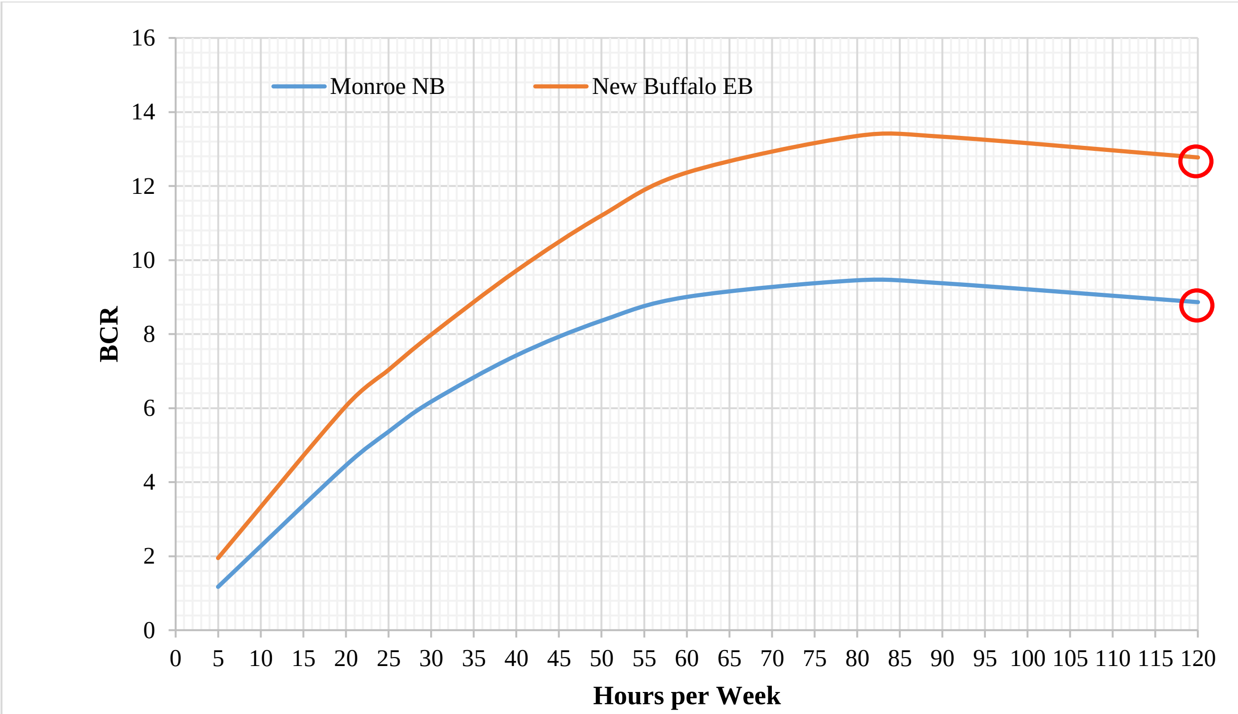


Figure 6.4 Impact of opening hours on BCR for most advanced fixed weigh stations

Table 6-2 Impact of operation hours on BCR based on existing conditions

Weigh Station	BCR Values for Various Hours of Operation Per Week									
	5-Hrs	**20-Hrs**	**25-Hrs**	**30-Hrs**	**40-Hrs**	**50-Hrs**	**60-Hrs**	**80-Hrs**	**90-Hrs**	**120-Hrs**
Monroe NB	1.17	4.45	5.36	6.17	7.42	8.36	9	9.45	9.37	8.86
New Buffalo EB	1.95	6.05	7.03	7.98	9.71	11.2	12.36	13.35	13.33	12.77
Coldwater NB	0.52	1.61	1.94	2.14	2.5	2.75	2.9	2.91	2.86	2.67
Monroe SB	1.23	4.48	5.36	6.12	7.28	8.12	8.68	9.02	8.91	8.34
New Buffalo WB	1.7	5.35	6.25	7.12	8.71	10.09	11.17	12.12	12.33	11.65
Grass Lake EB	0.61	2.13	2.52	2.84	3.33	3.68	3.9	4	3.93	2.92
Grass Lake WB	0.67	2.27	2.67	3	3.49	3.83	4.04	4.11	4.03	3.71
Ionia EB	-0.19	-0.53	-0.6	-0.66	-0.74	-0.79	-0.84	-0.91	-0.99	-1.02
Ionia WB	-0.19	-0.53	-0.6	-0.66	-0.74	-0.79	-0.84	-0.91	-0.99	-1.02
Fowlerville WB	-0.06	-0.16	-0.18	-0.2	-0.23	-0.27	-0.3	-0.34	-0.36	-0.38
Fowlerville EB	-0.06	-0.16	-0.18	-0.2	-0.23	-0.27	-0.3	0.34	-0.36	-0.38
Cambridge	0.1	0.23	0.25	0.27	0.29	0.3	0.3	0.29	0.28	0.25
Pontiac SB	-0.23	-0.28	-0.31	-0.33	-0.36	-0.36	-0.37	-0.37	-0.37	-0.36
Powers	0.68	1.48	1.6	1.69	1.85	1.93	1.95	1.7	1.56	1.3
Telegraph	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

6.2.2 Upgrading with Low-Speed WIM and Bypass Lane

Out of the 15 fixed weigh stations in Michigan, two are most advanced (i.e., with pre-clearance systems) and five are advanced (i.e., with bypass lane) as shown in Table 6.1. Life cycle analysis of individual fixed weigh stations as shown in Table 6.1 indicated that the most advanced and advanced fixed weigh stations are economically beneficial. In this section, the analysis on economic benefits of upgrading the basic and intermediate fixed weigh stations to advanced, was performed. Addition of a bypass lane depends on the existing configuration. For example, the configuration of Powers (Figure 4.2), Cambridge (Figure 4.3) and Telegraph (Figure 4.5) fixed weigh stations may not allow addition of a conventional bypass lane since they are on non-freeway routes. Therefore, upgrading existing fixed weigh stations to advanced level was analyzed for Ionia (EB and WB), Fowlerville (EB and WB) and Pontiac (SB).

Upgrading costs needed for each fixed weigh station were determined and benefits resulting from the new configurations were quantified. Table 6.3 presents the BCR results expected after upgrading (highlighted with green) as well as the original BCR before upgrading. As it can be seen, upgrading these four fixed weigh stations to the advanced level (i.e., adding bypass lanes) will improve their BCR significantly. According to recent MDOT’s condition assessment report, Ionia fixed weigh station needs improvements similar to Fowlerville except the ramps. As a result, although the two locations have similar traffic conditions, upgrading Ionia to advanced level will result in slightly higher benefits than Fowlerville as evidenced by the BCRs.

Table 6-3 Benefit-cost analysis results for upgrading to advanced

Fixed Weigh Station	Highway	Current Level	Current BCR	Advanced BCR
New Buffalo_EB	I-94 EB	Most Advanced	12.77	N/A
Monroe_NB	I-75 NB	Most Advanced	8.86	N/A
New Buffalo_WB	I-94 WB	Advanced	10.09	10.09
Monroe_SB	I-75 SB	Advanced	8.91	8.91
Grass Lake_EB	I-94 EB	Advanced	4.00	4.00
Grass Lake_WB	I-94 WB	Advanced	4.11	4.11
Coldwater_NB	I-69 NB	Advanced	1.94	1.94
Ionia_WB	I-96 WB	Intermediate	-0.84	2.01
Ionia_EB	I-96 EB	Intermediate	-0.84	2.01
Fowlerville_EB	I-96 EB	Intermediate	-0.30	1.46
Fowlerville_WB	I-96 WB	Intermediate	-0.30	1.46
Powers	US-41 & US-2	Basic	1.48	N/A
Pontiac_SB	I-75 SB	Basic	-0.31	1.14
Telegraph	US-24 NB & SB	Basic	0.00	N/A
Cambridge	M-50 & US-12	Basic	0.33	N/A

6.2.3 Installing Preclearance Systems

Preclearance systems such as PrePass reduce the number of commercial vehicles required to enter the static scale by allowing pre-screened compliant trucks to continue in the mainline without entering the fixed weigh station. This allows compliant trucks to continue traveling at the mainline speed and hence saving a great deal of travel time to truckers. Currently, there are two fixed weigh stations in Michigan equipped with preclearance systems. These are Monroe northbound and New Buffalo eastbound. To upgrade advanced fixed weigh station to the most advanced level requires only the installation of the preclearance system since they already have the mainline WIMs. For intermediate fixed weigh stations (which already have mainline WIM), two options exist:

1. Add low-speed WIM and bypass lane in addition to preclearance system
2. Add preclearance system without low-speed WIM and bypass lanes

For basic fixed weigh stations, the addition of mainline WIM is needed to install the preclearance systems. The two options regarding low-speed WIM and bypass lane listed above are also applicable to basic fixed weigh stations.

Table 6-4 presents the BCR results for option 1 (adding low-speed WIM and bypass lane in addition to preclearance system). Note that for basic fixed weigh stations this option includes adding a mainline WIM. The results show a comparison of the BCRs for existing condition and upgraded condition. As it can be seen from Table 6-4, installing preclearance systems at advanced fixed weigh stations will have a marginal increase in the BCR at four fixed weigh stations (New Buffalo WB, Monroe SB, Grass Lake EB, and Grass Lake WB). However, installing a preclearance system at Coldwater may likely decrease its BCR marginally. The decline of BCR at Coldwater can be explained by the fact that adding the preclearance system will add installation and maintenance costs while not significantly changing the number of violators caught. Figure 6.5 shows these marginal changes in BCR pictorially.

Table 6-4 Benefit-cost analysis results for installing preclearance systems

Fixed Weigh Station	Highway	Current Level	Current BCR	Advanced BCR	Most Advanced BCR
New Buffalo_EB	I-94 EB	Most Advanced	12.77	N/A	12.77
Monroe_NB	I-75 NB	Most Advanced	8.86	N/A	8.86
New Buffalo_WB	I-94 WB	Advanced	10.09	10.09	10.22
Monroe_SB	I-75 SB	Advanced	8.91	8.91	9.61
Grass Lake_EB	I-94 EB	Advanced	4.00	4.00	4.24
Grass Lake_WB	I-94 WB	Advanced	4.11	4.11	4.24
Coldwater_NB	I-69 NB	Advanced	1.94	1.94	1.73
Ionia_WB	I-96 WB	Intermediate	-0.84	2.01	1.99
Ionia_EB	I-96 EB	Intermediate	-0.84	2.01	1.99
Fowlerville_EB	I-96 EB	Intermediate	-0.30	1.46	1.49
Fowlerville_WB	I-96 WB	Intermediate	-0.30	1.46	1.49
Powers	US-41 & US-2	Basic	1.48	N/A	N/A
Pontiac_SB	I-75 SB	Basic	-0.31	1.14	0.41
Telegraph	US-24 NB & SB	Basic	0.00	N/A	N/A
Cambridge	M-50 & US-12	Basic	0.33	N/A	N/A

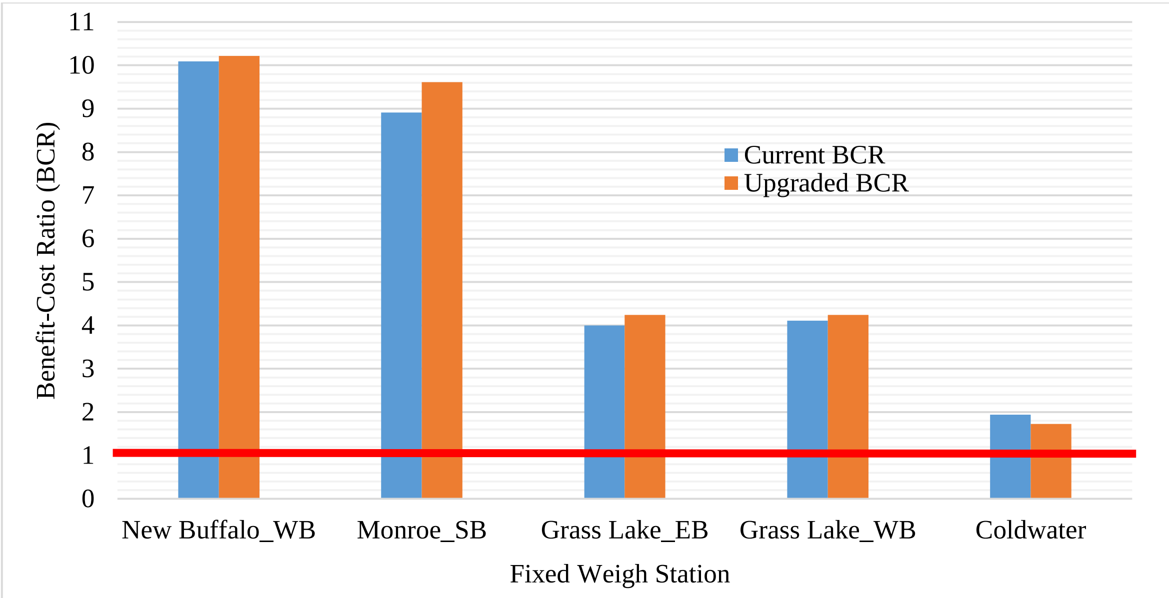


Figure 6.5 Comparison of BCR for before and after upgrading advanced to most advanced

For intermediate and basic fixed weigh stations (Figure 6.6), upgrading to advanced and most advanced shows that Ionia fixed weigh station (EB and WB), Fowlerville fixed weigh station (EB and WB) and Pontiac fixed weigh station (SB) would become economically beneficial if upgraded to advanced level (i.e., add low-speed WIM and bypass lane). However, upgrading to the most advanced level (i.e., adding preclearance system) does not seem to add significant value. In fact, while converting Pontiac fixed weigh station to advanced level would make it economically beneficial, converting it to most advanced level would not be beneficial as the BCR would drop below 1.0. This is because the current working hours are not enough to justify conversion to the most advanced level. Operating hours should also be increased if converting to the most advanced level is considered.

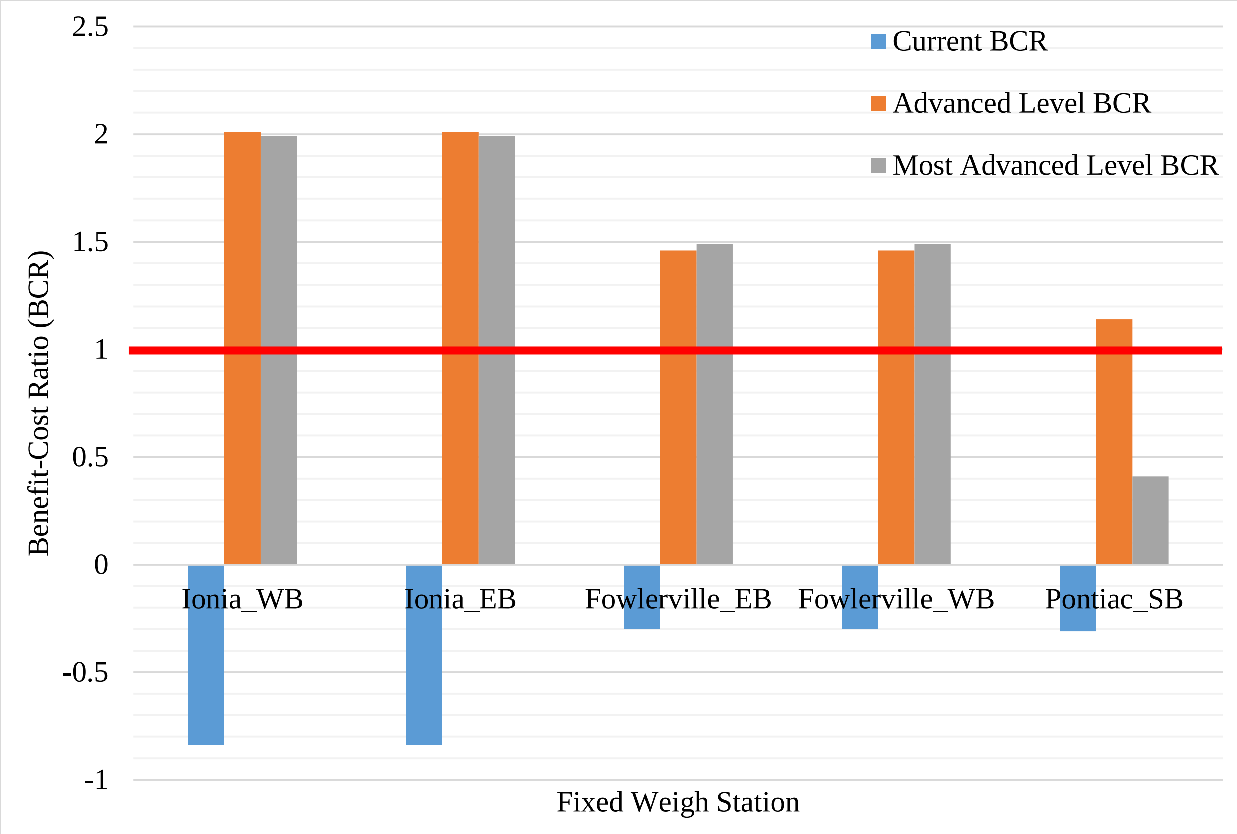


Figure 6.6 BCR results for before and after upgrading basic/intermediate FWS to advanced or most advanced FWS

An alternative to improving current basic and intermediate fixed weigh stations is to add preclearance system without adding low-speed WIM and bypass lanes. This has the potential to increase throughput at the fixed weigh station at relatively low cost. It can allow a significant number of compliant trucks to bypass the fixed weigh station and therefore minimize the delay and congestion caused by the requirement for each truck (including compliant trucks) to enter the scale facility. However, while there are data showing the percentage of trucks using PrePass at state boundary fixed weigh stations (New Buffalo EB and Monroe NB), it is not clear what percentage of trucks with preclearance registration will utilize interior fixed weigh stations. Assuming the same percentage of trucks as currently observed at Monroe NB and New Buffalo EB, benefit-cost analysis for improving intermediate fixed weigh stations (Fowlerville and Ionia) and basic fixed weigh station (Pontiac) by adding preclearance system without adding bypass lane, was conducted. Table 6-5 presents comparative BCR values for upgrading these fixed weigh stations using the two alternative approaches. Although the BCR values indicate a potential significant improvement by adding a preclearance system without adding bypass lane, it is very important to assess this approach in details prior to adoption to identify the accurate percentage of truckers willing to subscribe to the preclearance system if installed.

Table 6-5 Comparative analysis for adding preclearance system to basic/intermediate FWS

Fixed Weigh Station	Highway	Current Level	Current BCR	Advanced Level BCR	Most Advanced BCR (with bypass lane)	Most Advanced BCR (without bypass lane)
Ionia_WB	I-96 WB	Intermediate	-0.84	2.01	1.99	2.41
Ionia_EB	I-96 EB	Intermediate	-0.84	2.01	1.99	2.41
Fowlerville_EB	I-96 EB	Intermediate	-0.30	1.46	1.49	1.80
Fowlerville_WB	I-96 WB	Intermediate	-0.30	1.46	1.49	1.80
Pontiac_SB	I-75 SB	Basic	-0.31	1.14	0.41	1.55

6.2.4 Replacing Fixed Weigh Stations with Advanced Mobile Weight Enforcement

In advanced mobile enforcement, an officer connect wirelessly to the WIM sensor using a laptop computer in the vicinity of the WIM. Once a commercial vehicle is identified to be overweight, the officer directs the truck operator to a nearby safe location for weighing (and inspection, if necessary). The use of pavement cutout/notches is extremely beneficial by reducing the time needed to weigh a truck. However, since officers have to chase each vehicle identified as overweight, this strategy may only catch a fraction of the potential violators.

This study evaluated the potential to replace existing fixed weigh stations with advanced mobile enforcement. The advanced mobile enforcement approach incorporates roadside technologies necessary for identifying commercial vehicles. An average of two trucks per hour was used to estimate the benefits and costs of this approach. Assuming that the mobile enforcement is conducted for the same amount of time as the existing fixed weigh station, the benefits and costs were estimated. Based on the current operation of mobile enforcement in Michigan, it was estimated that a law enforcement officer can identify, chase, and process one truck in 30 minutes. This time includes returning to the WIM site. Pavement saving as well as travel time delays were computed based on the number of trucks an officer can process per given time. Table 6-6 presents the BCR results for each fixed weigh station and for its corresponding mobile enforcement alternative. As it can be seen, advanced mobile enforcement is not a feasible strategy to replace fixed weigh stations in Michigan. The low BCR values are the results of relatively lower capture rate by one officer conducting mobile enforcement compared to one officer when stationed at a fixed weigh station. This suggests that mobile enforcement needs to be a supplemental strategy, combined with fixed static scale by focusing on potential bypass routes to increase visibility of police officers and deter potential bypassing problem.

Table 6-6 Benefit-cost analysis results for replacing FWS with mobile enforcement

Fixed Weigh Station	Highway	Current Level	Current FWS BCR	Mobile Enforcement BCR
New Buffalo_EB	I-94 EB	Most Advanced	12.77	0.80
Monroe_NB	I-75 NB	Most Advanced	8.86	0.39
New Buffalo_WB	I-94 WB	Advanced	10.09	0.66
Monroe_SB	I-75 SB	Advanced	8.91	0.37
Grass Lake_EB	I-94 EB	Advanced	4.00	0.14
Grass Lake_WB	I-94 WB	Advanced	4.11	0.14
Coldwater_NB	I-69 NB	Advanced	1.94	0.18
Ionia_WB	I-96 WB	Intermediate	-0.84	0.21
Ionia_EB	I-96 EB	Intermediate	-0.84	0.21
Fowlerville_EB	I-96 EB	Intermediate	-0.30	0.18
Fowlerville_WB	I-96 WB	Intermediate	-0.30	0.18
Powers	US-41 & US-2	Basic	1.48	0.43
Pontiac_SB	I-75 SB	Basic	-0.31	0.18
Telegraph	US-24 NB & SB	Basic	0.00	0.01
Cambridge	M-50 & US-12	Basic	0.33	0.05

6.2.5 Adding/Removing Fixed Weigh Stations

Analysis results of Section 6.2.1 provide insight to criteria for removing fixed weigh stations. It is apparent that basic and intermediate configurations are associated with the lowest benefit-cost ratios, except Powers which is unique due to its location. In fact, the positive BCR associated with Powers fixed weigh station indicates that coverage of fixed weigh stations has impact on their BCR values. Redundant fixed weigh stations are most likely to have lower BCR values.

Analyses in Section 6.2.2 and Section 6.2.3 provide further information on necessary steps and considerations needed for the decision to remove fixed weigh stations. As it can be seen, some basic and intermediate fixed weigh stations which are not economically beneficial in their current condition can benefit from upgrading to higher levels. However, due to their current location and configurations, Telegraph and Cambridge fixed weigh stations cannot be upgraded to higher levels. Detailed sensitivity analysis on the impact of operation time on their economic benefits showed that revising hours of operation will not improve their economic benefits.

A number of factors should be considered when evaluating the addition or removal of fixed weigh stations. Traffic volume is one essential and critical factor in locating enforcement sites, specifically fixed weigh stations. Since these facilities require continual staffing, there exists a minimum traffic volume below which the return on investment does not support a fixed station at that location. Other critical factors for locating a fixed weigh station include whether the location is a state boundary and the highway functional class. The highway functional class is also correlated with truck volume.

In order to determine the minimum truck traffic volume to economically locate a fixed weigh station, a detailed sensitivity analysis of advanced and most advanced levels was conducted. As it can be seen, Figure 6.7 presents the minimum commercial average daily traffic (CADT) for locating advanced and most advanced fixed weigh stations. The minimum CADT to locate the advanced and most advanced fixed weigh stations is considered to be 2,200. It should be noted that basic and intermediate fixed weigh station configurations are uneconomical because of their low capture rate and high level of delay for truck drivers. As a result of these analyses, this study recommend that Cambridge and Telegraph be considered for further evaluation for removal.

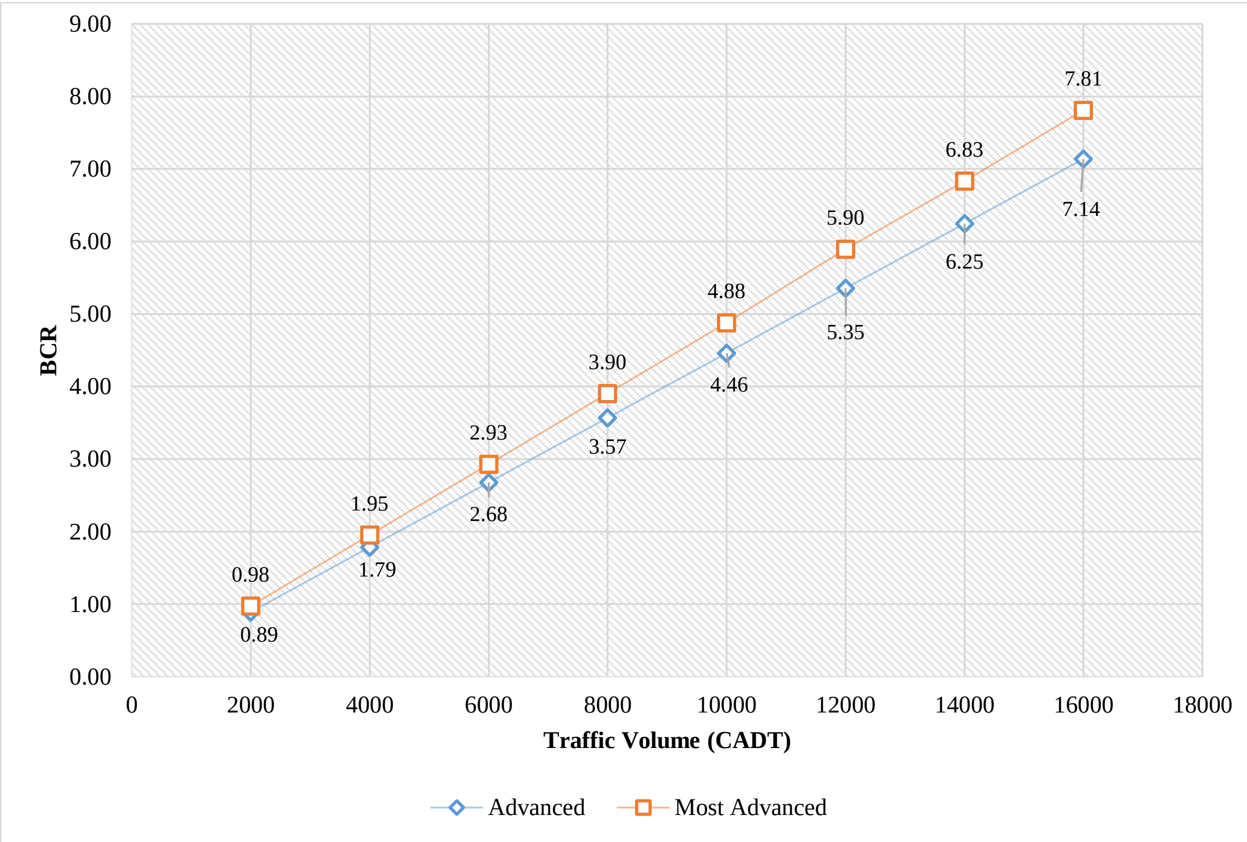


Figure 6.7 Minimum CADT for locating a fixed weigh station

Adding a fixed weigh station requires analysis of the existing fixed weigh stations, potential bypass routes, as well as locations with higher violation rates. As discussed above, truck volume, state boundary, as well as highway functional class should be highly considered. It is also important to consider the current network coverage of the existing fixed weigh station. Examining the CADT map as well as potential overweight commercial vehicles recorded by the WIMs across the state indicated that there is significant network coverage by fixed weigh stations in the Southeast part of the state, even with Telegraph and Cambridge fixed weigh stations removed. Examining region by region CADT values and recorded overweight percentages, the southwest part of Grand region may benefit from the addition of one fixed weigh station. While specific location depends on the availability of the right of way, I-196, I-96 or US-31 (shown in the map in Figure 6.8) may be potential candidate locations. However, it is imperative that a detailed study of truck origin-destination be conducted to ascertain the need to add a new fixed weigh station in this area. Maps showing details for other regions are shown in Appendix 6.3.

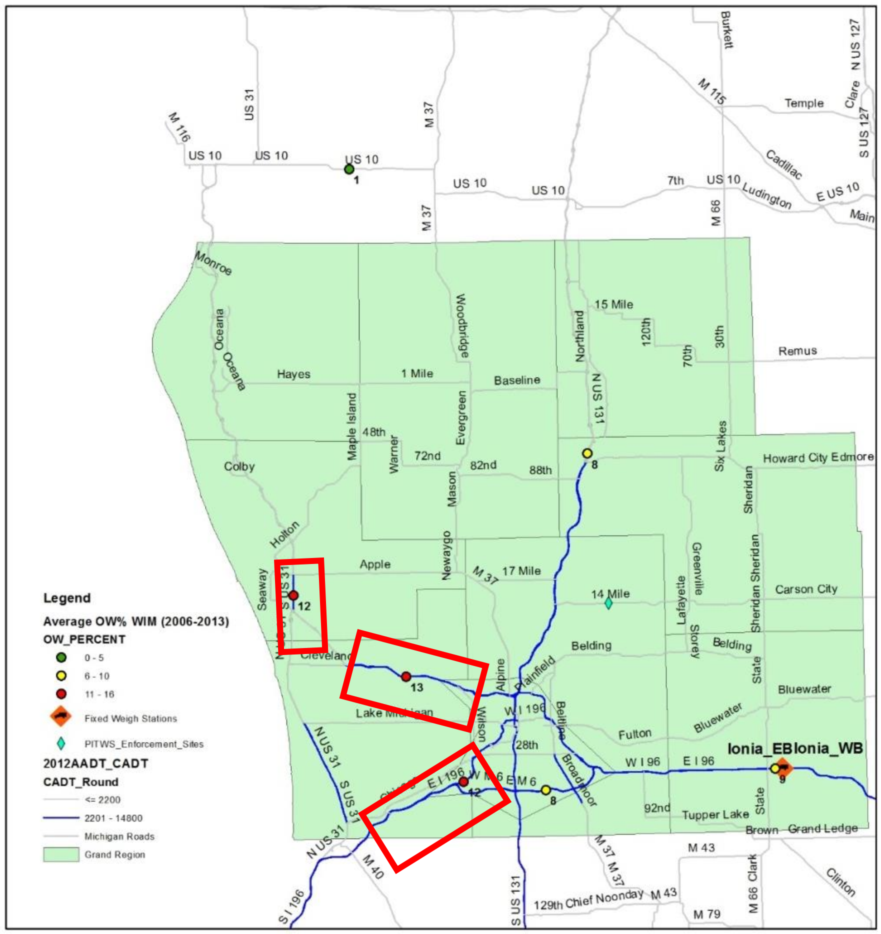


Figure 6.8 Potential locations to add a fixed weigh station

6.2.6 Summary and Findings of Benefit-Cost Analysis

This chapter presented the benefit-cost analysis results for alternative strategies for commercial vehicle enforcement. Life cycle cost analyses were performed for each of the existing fixed weigh stations and alternative approaches such as mobile enforcement strategy. Fixed weigh stations were grouped into four levels (basic, intermediate, advanced and most advanced) depending on what features were present. In general terms, the basic fixed weigh station consisted of just a static scale while the intermediate level weigh station had a mainline WIM present. The advanced level fixed weigh station had a low-speed WIM and bypass lane present, while the most advanced fixed weigh station had a preclearance system.

Analysis of the 15 existing fixed weigh stations indicated that:

- The two most advanced fixed weigh stations (Monroe NB and New Buffalo EB) are economically beneficial (with BCR values of 8.86 and 12.77, respectively). This can be attributed to their ability to focus on potential violators while allowing compliant trucks to bypass the fixed weigh station, either through mainline (if subscribed to PrePass, or through a bypass lane if detected to comply with regulations).
- All advanced level fixed weigh stations (New Buffalo WB, Monroe SB, Grass Lake EB, Grass Lake WB, and Coldwater) are economically beneficial with BCR values greater than 1.00. However, it should be noted that Monroe SB and New Buffalo WB catch violators who are leaving the state of Michigan.
- Intermediate fixed weigh stations at Fowlerville and Ionia may be generating greater disbenefits due to their inability to handle the truck volume present with their current configuration which requires all trucks to enter the fixed weigh station. Further analysis on whether revising the number of hours the stations are open can improve their benefits revealed that they will still be uneconomical regardless of changes in the schedule.
- All basic fixed weigh stations (except Powers) were found to be uneconomical with BCR values of less than 1.00. Powers, the only fixed weigh station in the Upper Peninsula, is one of the most isolated fixed weigh stations such that an overweight truck caught at this station would have potentially travelled a longer stretch of highway before being caught, hence damaging more pavement. Similar to the intermediate level, further analysis on whether revising the operation schedule can improve their benefits revealed that they will still be uneconomical regardless of changes in the schedule.

Upgrading of current intermediate fixed weigh stations (Ionia and Fowlerville) and one basic fixed weigh station (Pontiac) to the advanced level (i.e., adding a bypass lane) was analyzed. The other three basic fixed weigh stations (Powers, Telegraph and Cambridge) were not considered for upgrading to the advanced level due to their current configurations, which make it impractical to add a bypass lane. Upgrading these five fixed weigh stations (Fowlerville EB, Fowlerville WB, Ionia EB, Ionia WB, and Pontiac SB) to the advanced level will improve their performance significantly and make them economically beneficial (with BCR values greater than 1.00).

Preclearance systems such as PrePass reduce the number of commercial vehicles required to enter the static scale by allowing pre-screened compliant trucks to continue in the mainline without entering the fixed weigh station. This allows compliant trucks to continue traveling at the mainline speed and hence saving a great deal of travel time to truckers while allowing officers to focus on potential violators. Analysis results for upgrading fixed weigh stations by adding preclearance systems showed that:

- While Monroe SB, New Buffalo WB, Grass Lake EB, and Grass Lake WB fixed weigh stations would have slightly improved economic benefits, Coldwater would become less beneficial (BCR value changing from 1.94 to 1.73). The decline of benefits at Coldwater can be explained by the fact that adding the preclearance system will add installation and maintenance costs while not significantly changing the number of violators caught.
- While installing preclearance systems (together with adding bypass lanes) at Fowlerville EB and Fowlerville WB fixed weigh stations would improve their current economic benefits, the improvement will not be significantly different from when just a bypass lane is added.
- Comparing the benefits gained by improving Ionia EB and Ionia WB to the most advanced (adding preclearance) to just advanced (adding a bypass lane only) showed that adding a preclearance system would reduce economic benefits.

- For the Pontiac fixed weigh station, adding a preclearance system together with a bypass lane will result in reduced economic benefits compared to when only a bypass lane is added.
- An alternative to adding both a bypass lane and a preclearance system to the existing basic and intermediate fixed weigh stations is to just add a preclearance system. This can allow a significant number of compliant trucks to bypass the fixed weigh station (if precleared) and therefore minimize the delay and congestion caused by the requirement for each truck (including compliant trucks) to enter the scale facility. Economic analysis indicated that this approach could be even more economically beneficial. However, this approach requires a more detailed assessment of what proportion of truckers are willing to subscribe to the preclearance program, especially for fixed weigh stations utilized predominantly by intrastate tucks. Economic analysis in this study assumed the average proportion observed currently at Monroe NB and New Buffalo EB fixed weigh stations.

Analysis of mobile enforcement strategies indicated that the approach plays a very important role in increasing visibility of law enforcement officers and therefore deters potential violation of commercial vehicle laws. Law enforcement visibility also deter potential use of routes bypassing a given fixed weigh station. However, these benefits cannot be quantified. Using the quantifiable costs and benefits, the results indicated that mobile enforcement cannot replace fixed weigh stations. Mobile enforcement using wireless WIMs should be used to supplement fixed weigh stations by focusing on potential bypass routes, especially where criteria for locating a fixed weigh station are not met.

A decision to add or remove fixed weigh stations should be guided by the answers to two specific questions:

1. Are the existing fixed weigh stations economically beneficial in their current or improved conditions?
2. Are there areas/locations which meet specific criteria for locating fixed weigh stations but currently have none (i.e., coverage)?

Analysis of costs and benefits of existing fixed weigh stations (Section 6.2.1) indicated that Cambridge and Telegraph fixed weigh stations are not economically beneficial in their current conditions. The results also indicated that upgrading them to advanced levels may be impractical. Therefore, the two fixed weigh stations are good candidates to be considered for removal.

Results of the survey of other states and Canada as well as literature review indicated that three major factors for deciding to locate a fixed weigh station include traffic volume, state boundary, and highway functional class. Also, the potential violation rate is important when deciding to locate an enforcement site. Sensitivity analysis results indicated that basic and intermediate fixed weigh stations are uneconomical designs. For the advanced and most advanced fixed weigh stations, the results indicated that the minimum commercial vehicle average daily traffic (CADT) to locate a fixed weigh station is 2,200. Examination of the above factors revealed that the southwest part of Grand region (northwest or southwest of Grand Rapids) may benefit from the addition of one fixed weigh station. The specific location depends on availability of the right of way. Also, a specific study focusing on truck travel paths may be needed to confirm the need to add a new fixed weigh station in this area.

Check-lane operation is another very important operation which focuses on safety and credentialing. Since its operation is analogous to that of basic fixed weigh stations, and since it does not focus on overweight violations, it is difficult to quantify the benefits. Although its operation is similar to that of basic fixed weigh stations (where all trucks are required to enter), the key difference between the two is the focus of enforcement. Check-lane operations increase the visibility of law enforcement officers while conducting safety inspections. The operations also act as a deterrence to violation of Michigan laws. It is also recommended that this operation be continued with its current focus.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary of Research

Growth of truck traffic in Michigan is driven by many factors related to economic activities and the need for freight shipping. Growth in truck traffic is associated with increase in the need to improve commercial vehicle enforcement strategies to ensure compliance to state weight, size and safety laws. Fixed weigh stations are the traditional locations to enforce commercial vehicle laws. Due to limitations of traditional fixed weigh stations (stations where all commercial vehicles are required to enter), there have been many efforts in the United States to improve commercial vehicle enforcement strategies by adopting new technologies. These technologies either replace or enhance fixed weigh stations.

Similar to other states, the Michigan State Police (MSP) mainly utilizes fixed weigh stations to enforce Michigan commercial vehicle laws. Other strategies utilized by MSP include mobile screening and check-lane operations. The Michigan Department of Transportation provides and maintains facilities utilized by MSP to enforce commercial vehicle laws. However, due to limited transportation revenues, MDOT and MSP needed to determine the effectiveness of existing fixed weigh stations and the use of alternative technologies and enhancements to further protect and maximize the life span of the State's road network.

The primary goal of this study was to define the benefits of each of the existing fixed weigh stations in Michigan, the cost of upgrading, enhancing and maintaining these weigh stations, and the cost of using alternative solutions in place of fixed weigh stations or as an enhancement to it. Benefit cost analyses were performed to help MDOT and MSP in decision making on future commercial vehicle enforcement strategies.

To accomplish the goals of this study, a comprehensive literature review was performed to identify the current practices in US states and other countries. Furthermore, an online survey was administered to all US state’s commercial vehicle enforcement agencies and selected provinces in Canada. The survey was aimed at understanding any recent and planned improvements implemented by other states and Canada. Existing MDOT and MSP reports were reviewed to understand the current Michigan commercial vehicle enforcement strategies. Site visits of selected fixed weigh stations and other enforcement sites were performed to gain first-hand understanding of Michigan's commercial vehicle enforcement operations. An additional visit to a fixed weigh station in Indiana (Lowell fixed weigh station, located on I-65) was performed to identify any physical and operational differences between Michigan and Indiana fixed weigh stations. Cost data for each fixed weigh stations were collected from MDOT and MSP while conservative estimate of benefits of enforcement strategies was performed through analysis of existing WIM data, crash data, and operational characteristics of these strategies. Benefit-cost analyses were finally performed to compare identified alternative strategies, improvements and upgrades.

7.2 Conclusions

Through the literature review, it was determined that fixed weigh stations still remain as the main locations for enforcing commercial vehicle laws in many US states and other countries. However, these fixed weigh stations are enhanced and improved to increase their efficiency. The main improvements and enhancements include the use of WIM (mainline and ramp) and preclearance systems. The mainline WIM facilitates the use of preclearance systems while the ramp WIM (low-speed/sorting WIM) facilitates the use of a bypass lane. Using preclearance systems reduce the number of commercial motor vehicles (CMVs) entering the fixed weigh station through mainline screening of weight, size, and credentials at freeway speeds. Compliant CMVs may bypass the fixed weigh station at freeway speed unless they are selected randomly to enter the fixed weigh station. Adding a low speed WIM with a bypass lane is very beneficial at congested fixed weigh stations because it increases capacity and reduces congestion.

The literature review also revealed that states and other countries use WIM sensors to supplement (and in some cases to replace) fixed weigh stations by implementing mobile screening or virtual weigh stations (VWS). Other improvements and enhancements of fixed weigh stations include use of automatic vehicle identification (AVI) systems, use of cameras, use of over-height detectors and other improvements.

The literature review also revealed that a number of states and one province in Canada have their own state-specific preclearance systems. These include Weigh2GoBC (for British Columbia), NCPASS (for North Carolina), and Green Light (for Oregon). These systems reduce the number of trucks required to enter a fixed weigh station, thus allowing enforcement officers to focus on potential violators more effectively. Quantification of the benefits of such state-specific preclearance systems may need to be explored in the future.

Furthermore, the literature suggested that efficiency of commercial vehicle enforcement officers can be significantly improved by utilizing technology integration and data consolidation systems. Integration of technologies and consolidation of data enables electronic identification and verification of safety compliance of commercial vehicles to ensure that officers focus their inspection resources on those vehicles, carriers and drivers most likely to present a significant safety risk. With the limited number of officers to staff enforcement locations, such technologies have the potential to increase efficiency of enforcement officers.

A number of previous studies have examined the safety impact of fixed weigh stations. The literature review revealed that presence of fixed weigh stations may lead to an increase in the number of crashes due to diverging and merging of commercial vehicles and speed differentials resulting from these maneuvers. However, these studies did not address the potential safety benefits associated with safety inspections of trucks. Heavy vehicles with defects (e.g., defective brakes) may be more likely to be involved in crashes downstream of the facility. Through commercial vehicle enforcement at fixed weigh stations, such defective trucks are removed from the traffic stream, potentially avoiding a crash.

A survey administered to other states and Canada revealed that:

- The majority of US states (95 percent) and Canadian provinces use fixed weigh stations for commercial vehicle enforcement.
- About one-third of states and provinces participating in the survey use mainline and low-speed WIMs to improve efficiency of commercial vehicle enforcement operations.
- Safety concerns as well as changes in traffic volume have led states and provinces to remove fixed weigh stations.

- The majority of states (85.7 percent) and provinces (60 percent) do not plan to remove fixed weigh stations in the near future.
- In addition to random and/or scheduled patrol on suspected routes, portable scales and virtual weigh stations (VWS) are used to mitigate the problem of violators bypassing fixed weigh stations.
- Truck volume, state boundary, and highway functional class are the major criteria for locating fixed weigh stations.
- More than half of the participating states and provinces use virtual weigh stations to enforce commercial vehicle laws
- Truck volume, high commercial vehicle violations, availability of utilities for power and communication, access to a safe pullover location, and close proximity to the fixed weigh station are the main criteria in the selection of locations for VWSs.
- The majority of participating US states (57 percent) and Canadian provinces (80 percent) use mobile enforcement strategy.
- Preclearance systems are used in many states (87.7 percent) and Canadian provinces (60 percent).
- About a quarter of US states and 80 percent of Canadian provinces participating in the survey employ check-lane operations as a strategy for enforcing commercial vehicle laws.
- A little over a third (38 percent) of US states participating in the survey use safe enforcement sites with pavement cut-outs/notches to facilitate the use of portable scales while 80 percent of provinces participating in the survey install pavement cut-outs/notches.

Examination of the current Michigan commercial vehicle enforcement strategies revealed that there are significant physical and operational differences among existing fixed weigh stations. It was therefore determined that four levels of fixed weigh stations can be established for planning purposes: Basic, Intermediate, Advanced and Most Advanced. A basic fixed weigh station has only a static scale, while an intermediate fixed weigh station consists of both a static scale and a mainline WIM. The advanced fixed weigh station consists of a low-speed WIM for sorting traffic as well as a bypass lane, in addition to the features present at intermediate stations. At the highest level, the most advanced fixed weigh station consists of all features of the advanced level, plus a preclearance system. The construction/installation costs by fixed weigh station levels was determined to range from $2.3 million to $3.3 million. The costs to upgrade each fixed weigh station were determined and presented. It is also worth noting here that location of the static scale (front vs back of the building) may have implication for the efficiency of a fixed weigh station. To that end, the fixed weigh stations with the static scale located at the back of the building (e.g., Monroe NB and New Buffalo WB) may have opportunities for improving their efficiency by reconfiguring the layout to relocate the static scales to the front.

Analysis of citations issued at existing fixed weigh stations indicated that citation fines at all fixed weigh station average about $1.6 million per year. Combining enforcement sites, the statewide citation fines average about $4.5 million per year.

Analysis of factors associated with benefits and costs of enforcement strategies indicated that pavement saving and travel time delays are the main factors affecting the economic value a given enforcement strategy. It was determined that the more the overweight trucks that can be captured without causing unnecessary delay to compliant commercial vehicles, the more the beneficial a strategy can be. The analysis indicated that the net safety benefit of fixed weigh stations is very minimal. While inspections conducted at fixed weigh stations reduce the likelihood of crashes involving defective commercial vehicles downstream of the station, presence of fixed weigh stations is associated with increases in crashes in the segment before the facility.

Analysis of the 15 existing fixed weigh stations indicated that:

- The two most advanced fixed weigh stations (Monroe NB and New Buffalo EB) are economically beneficial (with BCR values of 8.86 and 12.77, respectively). This can be attributed to their ability to focus on potential violators while allowing compliant trucks to bypass the fixed weigh station, either through mainline (if subscribed to PrePass, or through a bypass lane if detected to comply with regulations).
- All advanced level fixed weigh stations (New Buffalo WB, Monroe SB, Grass Lake EB, Grass Lake WB, and Coldwater) are economically beneficial with BCR values greater than

1.00. However, it should be noted that Monroe SB and New Buffalo WB catch violators who are leaving the state of Michigan.

- Intermediate fixed weigh stations at Fowlerville and Ionia may be generating greater disbenefits due to their inability to handle the present truck volume with their current configuration which requires all trucks to enter the fixed weigh station. Further analysis on whether revising the number of hours the stations are open can improve their benefits revealed that they will still be uneconomical regardless of changes in the schedule.
- All basic fixed weigh stations (except Powers) were found to be uneconomical with BCR values of less than 1.00. Powers, the only fixed weigh station in the Upper Peninsula, is one of the most isolated fixed weigh stations such that an overweight truck caught at this station would have potentially travelled a longer stretch of highway before being caught, hence damaging more pavement. Similar to the intermediate level, further analysis on whether revising the operation schedule can improve their benefits revealed that they will still be uneconomical regardless of changes in the schedule.

Upgrading the current intermediate fixed weigh stations (Ionia and Fowlerville) and one basic fixed weigh station (Pontiac) to the advanced level (i.e., adding a bypass lane) was analyzed. Upgrading these five fixed weigh stations to advanced level will significantly improve their performance significantly and make them economically beneficial (with BCR values greater than 1.00).

Analysis results for upgrading fixed weigh stations by adding preclearance systems showed that:

- While Monroe SB, New Buffalo WB, Grass Lake EB, and Grass Lake WB fixed weigh stations would have slightly improved economic benefits, Coldwater would become less beneficial (BCR value changing from 1.94 to 1.73). The decline of benefits at Coldwater can be explained by the fact that adding the preclearance system will add installation and maintenance costs while not significantly changing the number of violators caught.

- While installing preclearance systems (together with adding bypass lanes) at Fowlerville EB and Fowlerville WB fixed weigh stations would improve their current economic benefits, the improvement will not be significantly different from when just a bypass lane is added.
- Comparing the benefits gained by improving Ionia EB and Ionia WB to the most advanced (adding preclearance) to just advanced (adding a bypass lane only) showed that adding a preclearance system would reduce economic benefits.
- For the Pontiac fixed weigh station, adding a preclearance system (together with a bypass lane) will result in reduced economic benefits compared to when just a bypass lane is added.
- An alternative to adding both bypass lane and a preclearance system to the existing basic and intermediate fixed weigh stations is to just add preclearance system. This can allow a significant number of compliant trucks to bypass the fixed weigh station (if precleared) and therefore minimize the delay and congestion caused by the requirement for each truck (including compliant trucks) to enter the scale facility. Economic analysis indicated that this approach could be even more economically beneficial. However, this approach requires a more detailed assessment of what proportion of truckers are willing to subscribe to the preclearance program, especially for fixed weigh stations utilized predominantly by intrastate trucks. Economic analysis in this study assumed the average proportion observed currently at Monroe NB and New Buffalo EB fixed weigh stations.

Analysis of the mobile enforcement strategy indicated that the approach played a very important role in increasing the visibility of law enforcement officers and therefore deter potential violation of commercial vehicle laws. They also deter potential use of routes bypassing a given fixed weigh station. However, these benefits cannot be quantified. Using the quantifiable costs and benefits, the results indicated that mobile enforcement cannot replace fixed weigh stations. Mobile enforcement using wireless WIMs should be used to supplement fixed weigh stations by focusing on potential bypass routes, especially where criteria for locating a fixed weigh station are not met.

7.3 Recommendations

This study recommends the following:

- A number of fixed weigh stations be enhanced/upgraded to improve their economic value. Specifically, the study recommends that Ionia (eastbound and westbound), Fowlerville (eastbound and westbound), and Pontiac (southbound) fixed weigh stations be considered for upgrading to the advanced level (i.e., add low-speed WIM and bypass lane). Consideration to improve to the most advanced (i.e., adding preclearance system without adding low-speed WIM and bypass lane) can be made after an additional study to determine the potential proportion of truckers willing to subscribe to the service is conducted.
- With the exception of Powers fixed weigh station which is isolated, removal of fixed weigh stations from routes with CADT less than 2,200 be considered. Specifically, Cambridge and Telegraph fixed weigh stations should be considered for removal.
- Based on existing potential violation rates shown by WIM sensors and based on truck volume, adding one fixed weigh station in the southwest part of the Grand region should be considered. Although the specific location will depend on availability of the right of way, I-196, I-96 or US 31 may be potential candidate locations. However, further study of the origin-destination patterns of trucks traveling these routes will be needed to confirm the need to add a new fixed weigh station.
- Consider implementation of systems that integrate enforcement technologies and consolidate data to enable electronic identification and verification of safety compliance of commercial vehicles. This has the potential to improve efficiency by ensuring that officers focus their inspection resources on those vehicles, carriers and drivers most likely to present a significant safety risk. Fixed and mobile systems should be considered for implementation.
- Mobile screening should continue to be used as a supplemental strategy focusing on potential bypass routes with higher potential violation rates. This strategy, supplemented

with mobile systems of integrated technologies and data consolidation, have the potential to provide the necessary deterrence on routes unsuitable for fixed weigh station (e.g., those locations with higher violation rates, but CADT less than 2,200).

- Periodically review commercial vehicle traffic and routes to see where mobile weight enforcement should be applied. The decision to maintain a given enforcement site should be based on potential violation rate and coverage.
- Continue check-lane operations focusing on safety-related issues of commercial vehicles.
- Conduct further research on integration of technologies and consolidation of data to enhance commercial vehicle enforcement. Additional research is also needed to confirm the need to add a new fixed weigh station in the Grand region. It is also important to study the impact of the location of the sign informing truckers of the presence of a fixed weigh station one mile downstream. The current one mile distance may not be optimal. Finally, it is also beneficial to evaluate the possibility of Michigan to develop a statewide preclearance system such as GreenLight (used in Oregon) or Weigh2GoBC (used in British Columbia) or expanding the nationwide systems such as PrePass and DriveWyze. Such systems have the potential to increase the number of precleared commercial vehicles and relieve congestion at fixed enforcement locations.

Detailed recommendations for implementation of the research findings including a budget plan are provided in Appendix 7.1.

8 BIBLIOGRAPHY

Ahmed, A., Agbelie, B. R. D. K., Lavrenz, S., Keefer, M., Labi, S. and Sinha, K. C. (2013). Costs and Revenues Associated With Overweight Trucks in Indiana. Publication FHWA/IN/JTRP-2013/01. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2013. doi: 10.5703/1288284314987.

Ali, N., Trogdon, J., and Bergan, A. (1994) "Evaluation of piezoelectric weigh-in-motion system." Canadian Journal of Civil Engineering. Vol. 21, pp. 156-160.

B.C. Ministry of Transportation and Infrastructure. (n.d.). Weigh2GoBC. Retrieved June 2013, from http://www.th.gov.bc.ca/weigh2GoBC/

Banerjee, I., Lee, J., Jang, K., Pande, S., and Ragland, D. (2009). Rest Areas Reducing Accidents Involving Driver Fatigue. Report Prepared for the California Department of Transportation, Contract 65A0208, Task Order 6220. California.

Barnett, J. C., & Benekohal, R. F. (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, 1655(1), pp. 233-240.

Benekohal, R., El-Zohairy, Y., Forrler, E., and Aycin, M. (1999). Truck delay and traffic conflicts around weigh stations. Transportation Research Record, 1653, TRB, National Research Council, Washington D.C., pp. 52-60.

Benekohal, R., Y. El-Zohairy, E. Forrler, and M. Aycin. "Truck Delay and Traffic Conflicts Around Weigh Stations." Transportation Research Record. No. 1653. 1999, pp. 52-60.

Cambridge Systematics, Inc. (2009). Concept of Operations for Virtual Weigh Station. Final report prepared for Federal Highway Administration (FHWA). Available at http://ops.fhwa.dot.gov/publications/fhwahop09051/index.htm.

Chan, Y. C, Bunker, J. M., and Kumar, A. (2006). Overloading truck study and strategies to minimize it. In the proceedings of Faculty of Built Environment and Engineering Infrastructure Conference 2006. University of Technology, Queensland University of Technology, Brisbane, Qld.

Chin, H. C., and M. A. Quddus. (2003). Applying the Random Effect Negative Binomial Model to Examine Traffic Accident Occurrence at Signalized Intersections. Accident Analysis & Prevention 35: 253-259.

Evans, D., and Klashinsky, R. (2012). Weigh-in-Motion System for the Reduction of Commercial Vehicle Traffic Delays at the Borden-Carleton, PEI Weight Inspection Station. Traffic Operations and Management Session of the 2012 Annual Conference. Transportation Association of Canada.

FHWA (2009). Truck Size and Weight Enforcement Technologies: State of the Practice. A report prepared for the Federal Highway Administration (FHWA) by Cambridge Systematics, Cambridge, Massachusetts.

Garber, N. and Ehhert, A. (2000). The effect of speed, flow and geometric characteristics on crash rates for different types of Virginia highways. Virginia Transportation Research Council. Charlottesville, Virginia.

Garber, N. and Gadiraju, R. (1998). Factors affecting speed variance and its influence on accidents. AAA Foundation for Traffic Safety. Washington, D.C.

Gates, T. J., Savolainen, P. T., Datta, T. K., Todd, R. G., and Boileau, S. (2012). Evaluating the Appropriate Level of Service for Michigan Rest Areas and Welcome Centers Considering Safety and Economic Factors. Final Report - MDOT ORBP Project Number: OR10-045. Lansing, Michigan.

Gattis, J. L., Bryant, M. A., & Duncan, L. K. (2010). Truck Acceleration Speeds and Distances at Weigh Stations. Transportation Research Record: Journal of the Transportation Research Board, 2195(1), 20-26.

Green, P. E. (2009). Analysis of Data from the Thermal Imaging Inspection Systems Project. Report No. UMTRI-2009-38. The University of Michigan Transportation Research Institute, Ann Arbor, Michigan.

Hahn, D., and Pansare, M. (2009). Maryland Virtual Weigh Station. Final Report prepared for Maryland State Highway Administration, Motor Carrier Division. Available at http://sha.md.gov/OOTS/MD_VWS_Final_Report.pdf.

Han, L. D., Ko, S.-S., Gu, Z., & Jeong, M. K. (2012). Adaptive Weight-in-motion algorithm for truck weight enforcement. Transportation Research Part C, 256-269.

Hanson, H., Klashinsky, R., & McGibney, S. (2010). ITS Technologies for Commercial Vehicle Compliance in the Maritimes. 2010 Annual Conference of the Transportation Association of Canada Halifax, Nova Scotia.

Harkey, D. L., Robertson, D. H. and davis, S. E. (1990). Assessment of current speed zoning criteria. Transportation Research Record: Journal of the Transportation Research Board, 1281, pp. 40-51.

HELP Inc., (2015). 360SmartView. Available at: http://www.360smartview.com/. Accessed on 02/15/2015.

Hilbe, J.M. 2011. Negative Binomial Regression, Second Edition, Cambridge University Press, United Kingdom.

IIS, (2015). IIS SmartRoadside. Available at: http://www.intelligentimagingsystems.com. Accessed on 02/15/2015.

International Road Dynamics. (2006). "Mainline Sorting - Truck Bypass" Online Presentation. Internet. http://www.irdinc.com/english/pdf/ppt/mainline_bypass.pdf.

Ismail, K., Lim, C. and Sayed, T. (2010). Simulation and Evaluation of Automated Vehicle Identification at Weigh-in-Motion Inspection Stations. Transportation Research Board of the National Academies, Washington, D.C., 2010. pp. 140-150.

Jacob, B., and Beaumelle, V. F. (2010). Improving Truck Safety: Potential of weigh-in-motion technology. IATSS Research, No. 34, pp. 9-15.

Janson, B. N., Awad, W., Robles, J., Kononov, J., & Pinkerton, B. (1998). Truck accidents at freeway ramps: Data analysis and high-risk site identification. Journal of Transportation and Statistics, 1(1), 75-92.

Kamyab, A. (1998). "Weigh Stations' Capacity Enhancement Alternatives: A Comparison of Mainline Electronic Screening and Physical Expansion." 1998 Transportation Conference Proceedings, Center for Transportation Research and Education (CTRE), Iowa State University, Ames, Iowa.

Katz, B. J. (2001). Field and Modeling Framework for Evaluating Truck Weigh Station Operations. Masters Thesis, Virginia Polytechnic Institute and State University, Virginia.

Khorashadi, Ahmad. (1998). Effect of Ramp Type and Geometry on Accidents. Report FHWA/CA/TE-98/13.

Kissick, J. et al (2013). Kentucky's PRISM-Based Automated Ramp Screening System Evaluation. Research Report KTC-13-21/RSF27-12-1F. Kentucky Transportation Center. Lexington, KY.

Lee, J. B., Jaeckel, K., Choi, K., & Chow, G. (2013). Commercial Vehicle pre-clearance Programs: Current issues and recommendations for potential implementation. Transport Policy, Vol. 27, pp. 92-101.

Lee, J., Jaeckel, K., Choi, K., and Chow, G. (2013). Commercial vehicle pre-clearance programs: Current issues and recommendations for potential implementation. Transport Policy. Butterworth-Heinemann Ltd., 2013. pp 92-101.

Li, Z., and Sinha, K. C. (2000). A Methodology to Estimate Load and Non-Load Shares of Highway Pavement Routine Maintenance and Rehabilitation Expenditures. Publication FHWA/IN/JTRP-2000/04. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2000. doi: 10.5703/1288284313129.

Lord, D. (2006). Modeling motor vehicle crashes using Poisson-gamma models: Examining the effects of low sample mean values and small sample size on the estimation of the fixed dispersion parameter. Accident Analysis and Prevention 38: 751-766.

McBride, C., and Kirby, P. (2012). Strategic electronic monitoring and compliance of heavy commercial vehicles in the upper North Island. NZ Transport Agency Research Report 500. Wellington, New Zealand.

McCall, B., and Vodrazka Jr., W. C. (1997). State's Successful Practices Weigh-In-Motion Handbook. Federal Highway Administration (FHWA). Washington, D.C.

McCartt, A. T., Northrup, V. S., & Retting, R. A. (2004). Types and characteristics of ramp-related motor vehicle crashes on urban interstate roadways in Northern Virginia. Journal of Safety Research, 35(1), 107-114.

MDOT (2006). Michigan Department of Transportation State Long-Range Transportation Plan 2005-2030. Freight Profile Technical Report. Lansing, MI.

MDOT (2013). Michigan's Truck-Weight Law and Truck-User Fees. MDOT Intermodal Policy Division, retrieved August 2013 from https://www.michigan.gov/documents/mdot/MDOT_013-4-16TruckWeightsMichigan_418609_7.pdf.

Miaou, S.P., and H. Lum. (1993). Modeling vehicle accidents and highway geometric design relationships. Accident Analysis and Prevention 25: 689-709.

Michigan, L. C. (2014). Michigan Compiled Laws. Michigan. Retrieved June 2014 from https://www.legislature.mi.gov

MSP (2014). Commercial Vehicle Enforcement Overview. Retrieved from http://www.michigan.gov/msp/0,4643,7-123-59877-288534--,00.html. October, 2014.

NCPass (2013). NCPass preclearance system. Retrieved August 14, 2013, from http://www.ncpass.net/main.html

Noland, R.B., and M. A. Quddus. 2004. Analysis of pedestrian and bicycle casualties with regional panel data. Transportation Research Record: Journal of the Transportation Research Board 1897: 28-33.

ODOT (2013). Green Light Weigh Station Preclearance. Retrieved August 14, 2013, from http://www.oregon.gov/ODOT/MCT/pages/green.aspx.

Pezoldt, V. J., Koncz, N., & Obeng-Boampong, K. (2011). Benefits of Public Roadside Safety Rest Areas in Texas: Technical Report. Texas Transportation Institute, Texas A&M University System.

Pines, D., and Fang, C. (2008). A Study of Weigh Station Technologies and Practices. Report No. CT-2257-F-08-7. Prepared for Connecticut Department of Transportation. Available at http://docs.trb.org/01126513.pdf.

Podborochynski, D., Berthelot, C., Anthony, A., Marjerison, B., Litzenberger, R., Kealy, T., (2011). Quantifying Incremental Pavement Damage Caused by Overweight Trucks, Paper prepared for presentation at the Effects of Increased Loading on Pavement Session of the 2011 Annual Conference of the Transportation Association of Canada, Edmonton, Alberta.

Regan, A., park, M., nandiraju, S., and yang, C.H.Y. (2006). Strategies for Successful Implementation of Virtual Weigh and Compliance Systems in California. Institute of Transportation Studies, California PATH Research Report No. UCB-ITS-PRR-2006-19. Irvine, California. ISBN 1055-1425.

Salonen, S. (2012). Infrared Camera Application for the Testing of Heavy Truck Braking Systems. National Traffic Police of Finland, Helsinki, Finland. ISBN 978-952-249-098-8.

Santero, N., Nokes, W., and Harvey, J. (2005). Virtual Weigh Stations in California: A Preliminary Cost-Effectiveness Analysis. Report No. UCB-ITS-PWP-2005-5. Available at http://www.path.berkeley.edu/PATH/Publications/PDF/PWP/2005/pwp-2005-05.pdf

Solomon, D. (1964). Accidents on main rural highways related to speed, driver and vehicle. US Department of Commerce & Bureau of Public Roads. Washington, D.C.

SRF Consulting Group, Inc. ", (2007).Interstate Highway Safety Study: Analysis of Vehicle Crashes Related to Safety Rest Area Spacing". Minnesota Department of Transportation. Minnesota.

URS (2007). Virtual Weigh Station Demonstration. Final Report prepared for Minnesota Department of Transportation. Available at http://www.dot.state.mn.us/guidestar/2006_2010/virtual_weigh_station/MnDOT_VWS_Demo_Final_Report_080718.pdf

USDOT (2009). Swiss Heavy Goods Vehicle Control Centers: A Closer Look at Facility Characteristics and Supporting Technologies. U.S. Department of Transportation, Federal Highway Administration. Washington, D.C.

Washington, P. S., G. M. Karlaftis, and F. L. Mannering. 2011. Statistical and Econometric Methods for Transportation Data Analysis. 2nd Edition. Chapman & Hall/CRC, United States of America.

Yaacob, W. F. W., M. A. Lazim, and Y. B. Wah. (2011). Applying Fixed Effects Panel Count Model to Examine Road Accident Occurrence. Journal of Applied Sciences 11: 1185-1191.

Zhang, L., Hass , C., and Tighe, S. L. (2008). Evaluation of the Economic Feasibility of Weigh-In-Motion in Canada. Transportation Association of Canada. Toronto Ontario.

Zlatoper, T.J. (1989). Models explaining motor vehicle death rates in the United States. Accident Analysis and Prevention 21: 125-154.

9 APPENDICES

9.1 Appendix 3.1. Survey of Other States and Canada

Question 1: What is the name of your state/province?

Question 2: Does your state/province have a designated commercial vehicle enforcement unit?

United States		**Canada**	
No (%)	9.1%	No (%)	0%
Yes (%)	90.9%	Yes (%)	100%
I Don't Know (%)	0%	I Don't Know (%)	0%

<u>Question 3:</u> Does your state use Fixed weigh stations with static scale for commercial vehicle enforcement?

United States		**Canada**	
No (%)	4.5%	No (%)	0%
Yes (%)	95.5%	Yes (%)	100%
I Don't Know (%)	0%	I Don't Know (%)	0%

<u>Question 4:</u> How many fixed/static scale weigh stations are operational in your state?

United States		**Canada**	
Mean	15.86	Mean	18.6
Minimum	2	Minimum	8
Maximum	53	Maximum	39

<u>Question 5:</u> How many fixed/static scale weigh stations employ mainline Weigh in Motion (WIM) sensors?

United States		**Canada**	
Mean	4.75	Mean	1.80
Range 0-1	55.0%	Equal to 0	60.0%
Range 2-30	45.0%	Range: Higher than 0	40.0%
Minimum	0	Minimum	0
Maximum	30	Maximum	6

<u>Question 6:</u> How many fixed/static scale weigh stations employ low-speed (or ramp) weigh in Motion (WIM) sensors?

United States		**Canada**	
Mean	5.71	Mean	0.20
Range 0-1	33.3%	Equal to 0	80.0%
Range 2-8	47.6%	Range: Higher than 0	20.0%
Range 14-23	19.0%	-	-
Minimum	0	Minimum	0
Maximum	23	Maximum	1

<u>Question 7:</u> Have your state removed any fixed/static scale facilities from service in the past years?

United States		Canada	
No (%)	47.6%	No (%)	40%
Yes (%)	52.4%	Yes (%)	60%
I Don't Know (%)	0%	I Don't Know (%)	0%

Reasons for removing fixed weigh stations (Qn. 7):

- We closed an older (1950's era) weigh station on a secondary roadway. The station was on the south side of the roadway but monitored bi-directional traffic. It only had a single lane entering and exiting.
- Approximately 10 or so years ago, a fixed scale was removed on US 301 near Bushnell.
- Obsolete---safety concerns.
- Cost of major repairs, locations on longer on the high traffic routes, limited staff to operate.
- Maintenance issues.
- Staffing.
- The Minnesota Department of Transportation builds fixed weigh stations where they feel it would be most beneficial for weight enforcement. The Department of Public Safety, State Patrol, provides the enforcement personnel at the fixed scale facilities and actually operates the scales.
- Reduction in commercial traffic due to timber industry recession in two areas and new highway construction in 2 areas.
- They were located in the middle of the state or not on significantly traveled roadways.
- Limited staff positions and focus on port-of-entry locations.
- State has master plan of relocating sites to point-of-entry.
- Traffic safety issues Aging facilities with lack of funds to maintain or upgrade.
- One was removed during highway reconstruction, and has yet to be replaced. The other has been barricaded due to structural issues, awaiting a decision on whether or not to rehabilitate the site, or relocate it based on changing traffic patterns.
- Traffic congestion, move to mobile enforcement.
- Due to reconfiguration of the transportation network.

<u>Question 8:</u> Does your state plan to remove any fixed weigh station(s) in the near future?

United States		**Canada**	
No (%)	85.7%	No (%)	60%
Yes (%)	4.8%	Yes (%)	20%
I Don't Know (%)	10%	I Don’t Know (%)	20%

Reasons:

- No money to replace buildings or to purchase additional land.
- Besides the two alluded to above, one more site is slated to be relocated within five years.

<u>Question 9:</u> Does your state plan to add any new fixed weigh station in the near future?

United States		**Canada**	
No (%)	61.9%	No (%)	80%
Yes (%)	28.6%	Yes (%)	20%
I Don't Know (%)	10%	I Don't Know (%)	0%

Reasons:

- Three Virtual Weigh in Motion site on known by-pass routes that circumvent our Ports of Entry.
- We currently working WIM southbound and intend to upgrade northbound to WIM.
- To replace a facility that has been closed.
- A new site between Las Vegas and Fontana on Route 15 is to be built in the next three years.
- Actually, it is the demolition of buildings and reconstruction in the same site.
- New Interstate is under construction and we want to put the fixed station in a more effective location.

<u>Question 10:</u> Illegal bypassing of Fixed Weigh Stations by using alternative routes is a common problem, how does your state deal with this problem?

United States					
Use Virtual Weigh Station at bypassing routes		**Random/scheduled patrol on bypassing routes**		**Use Portable Weigh in Motion (PWIM) scales**	
No (%)	57.1%	No (%)	0.0%	No (%)	57.1%
Yes (%)	38.1%	Yes (%)	100.0%	Yes (%)	42.9%
I Don't Know (%)	4.8%	I Don't Know (%)	0.0%	I Don't Know (%)	0.0%
Canada					
Use Virtual Weigh Station at bypassing routes		**Random/scheduled patrol on bypassing routes**		**Use Portable Weigh in Motion (PWIM) scales**	
No (%)	100.0%	No (%)	0.0%	No (%)	100.0%
Yes (%)	0.0%	Yes (%)	100.0%	Yes (%)	0.0%
I Don't Know (%)	0.0%	I Don't Know (%)	0.0%	I Don't Know (%)	0.0%

United States				**Canada**	
We have no specific strategy		**Other**		**We have no specific strategy**	**Other**
No (%)	81.0%	No (%)	80.0%	No (%)	80.0%
Yes (%)	9.5%	Yes (%)	20.0%	Yes (%)	20.0%
I Don't Know (%)	9.5%	I Don't Know (%)	0.0%	I Don't Know (%)	0.0%

<u>Question 11:</u> Does your state operate all your fixed weigh stations 24 hours a day?

United States		**Canada**	
No (%)	90.5%	No (%)	100%
Yes (%)	9.5%	Yes (%)	0%
I Don't Know (%)	0%	I Don't Know (%)	0%

Reasons:

- Truck volume and staffing availability.

- Crash data and CMV traffic data.
- Statutory mandates.
- Hours based upon available manpower.
- Types of traffic.

Question 12: **Please rate by using the slider below how each factor shown influence the selection of locations for fixed site facilities for commercial vehicle enforcement.**

	United States				
	State Boundaries	**Highway Functional Class**	**Truck Volumes**	**Current/Future Freight Volumes/Activities**	**Others**
No	0%	0%	0%	0%	43%
No-Low	0%	0%	0%	10%	5%
Low	0%	0%	0%	0%	0%
Low-Medium	19%	5%	0%	5%	14%
Medium	0%	0%	0%	0%	0%
Medium-High	0%	29%	10%	33%	38%
High	29%	48%	48%	38%	0%
Very High	**52%**	**19%**	**43%**	**14%**	**0%**

	Canada				
	State Boundaries	**Highway Functional Class**	**Truck Volumes**	**Current/Future Freight Volumes/Activities**	**Others**
No	0%	0%	0%	0%	60%
No-Low	0%	0%	0%	0%	0%
Low	0%	0%	0%	0%	0%
Low-Medium	0%	20%	0%	0%	20%
Medium	0%	0%	0%	0%	0%
Medium-High	60%	20%	0%	40%	20%
High	20%	40%	80%	40%	0%
Very High	20%	20%	20%	20%	0%

Question 13: **Does your state use Portable Weigh in Motion (PWIM) scales?**

United States		**Canada**	
No (%)	63.6%	No (%)	80%
Yes (%)	36.4%	Yes (%)	20%
I Don't Know (%)	0%	I Don't Know (%)	0%

<u>Question 14:</u> Does your state use Virtual Weigh Stations (VWS) as a strategy for commercial vehicle enforcement in your state?

United States		**Canada**	
No (%)	45.5%	No (%)	40%
Yes (%)	54.5%	Yes (%)	60%
I Don't Know (%)	0.0%	I Don't Know (%)	0%

<u>Question 15:</u> How many Virtual Weigh Stations (VWS) does your state have?

United States		**Canada**
Mean	4.36	British Columbia has 10 and Manitoba has VWS. There is no significant comparison of the results since there are only two who were able to respond.
Range 1-2	45.5%	
Range 3-10	54.5%	
Minimum	1	
Maximum	12	

<u>Question: 16:</u> What are the main functional applications of your state's Virtual Weigh Stations (VWS)?

	United States				
	Truck size and weight enforcement	**Safety and credentialing regulations**	**Direct enforcement**	**Providing real-time traveler information to truck drivers**	**Other**
No	9.1%	0.0%	27.3%	90.9%	75.0%
Yes	90.9%	100.0%	63.6%	9.1%	0.0%
I Don't Know	0.0%	0.0%	9.1%	0.0%	25.0%

	Canada				
	Truck size and weight enforcement	**Safety and credentialing regulations**	**Direct enforcement**	**Providing real-time traveler information to truck drivers**	**Other**
No	0.0%	0.0%	33.3%	100.0%	100.0%
Yes	100.0%	100.0%	66.7%	0.0%	0.0%
I Don't Know	0.0%	0.0%	0.0%	0.0%	0.0%

<u>Question 17:</u> Please rate using the slider below how influential each criterion is in the selection of locations for virtual weigh station in your state.

U.S.A.									
Criteria	**No**	**No-Low**	**Low**	**Low-Medium**	**Medium**	**Medium-High**	**High**	**High-Very High**	**Very High**
High commercial vehicle violations	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	60.00%	0.00%	30.00%
High truck volume	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	60.00%	10.00%	30.00%
Location used as a bypass route from a nearby weigh station	10.00%	10.00%	0.00%	0.00%	0.00%	50.00%	20.00%	0.00%	10.00%
Close proximity to the weigh station	10.00%	0.00%	0.00%	20.00%	0.00%	30.00%	20.00%	10.00%	10.00%
Ease of intercept and short travel distance for enforcement officer	0.00%	0.00%	10.00%	10.00%	0.00%	50.00%	20.00%	10.00%	0.00%
Access to a safe pullover location for commercial vehicle	0.00%	0.00%	0.00%	10.00%	0.00%	40.00%	30.00%	0.00%	20.00%
Level stretch of road with fairly constant vehicle speeds	0.00%	0.00%	0.00%	20.00%	0.00%	50.00%	30.00%	0.00%	0.00%
Available utilities for power and communication	10.00%	0.00%	10.00%	20.00%	0.00%	10.00%	40.00%	0.00%	10.00%

Canada									
Criteria	**No**	**No-Low**	**Low**	**Low-Medium**	**Medium**	**Medium-High**	**High**	**High-Very High**	**Very High**
High commercial vehicle violations	0.00%	0.00%	0.00%	33.30%	0.00%	33.30%	33.30%	0.00%	0.00%
High truck volume	0.00%	0.00%	0.00%	33.30%	0.00%	33.30%	33.30%	0.00%	0.00%
Location used as a bypass route from a nearby weigh station	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Close proximity to the weigh station	33.30%	33.30%	0.00%	0.00%	0.00%	0.00%	33.30%	0.00%	0.00%
Ease of intercept and short travel distance for enforcement officer	33.30%	66.70%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Access to a safe pullover location for commercial vehicle	33.30%	66.70%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Level stretch of road with fairly constant vehicle speeds	33.30%	33.30%	0.00%	33.30%	0.00%	0.00%	0.00%	0.00%	0.00%
Available utilities for power and communication	0.00%	66.70%	0.00%	0.00%	0.00%	33.30%	0.00%	0.00%	0.00%

Question 18: **Do your state's Virtual Weigh Stations (VWS) use permanently installed WIM system or Portable Weigh in Motion (PWIM) systems?**

United States		Canada	
All use permanently installed WIM	72.7%	All use permanently installed WIM	66.7%
All use PWIM systems	0.0%	All use PWIM systems	0%
WIM and PWIM systems are used	27.3%	WIM and PWIM systems are used	33.3%

Question 19: **Do your state's Virtual Weigh Stations (VWS) employ advanced roadside-based technologies for automatic identification of violators?**

United States		Canada	
No (%)	36.4%	No (%)	80%
Yes (%)	63.6%	Yes (%)	20%
I Don't Know (%)	0.0%	I Don't Know (%)	0%

Technologies:

- USDOT Readers, License Plate Readers.
- Optical Character Recognition of the License Plate and DOT numbers with photo of violator containing WIM data.
- Computer-based programs that allow the officer to view the violations in real time.
- Photograph.

Question 20: **What is the average cost of deploying a basic Virtual Weigh Station-VWS?**
Without advanced roadside technologies:

- WIM only no photos, etc., $150,000
- $500,000.
- We have not installed a station in the last 6 years.
- $800,000.

With advanced roadside technologies:

- $400,000.
- $800,000.
- 500-650,000 depending on using an existing WIM or installing a new WIM.

Question 21: **Does your state plan to add more Virtual Weigh Stations (VWS) in the near future?**

United States		Canada	
No (%)	9.1%	No (%)	33%
Yes (%)	63.6%	Yes (%)	33%
I Don't Know (%)	27.3%	I Don't Know (%)	33%

<u>Question 22:</u> Does your state use Mobile Weight Enforcement at WIMs Sites as a strategy for commercial vehicle enforcement?

United States		**Canada**	
No (%)	42.9%	No (%)	0%
Yes (%)	57.1%	Yes (%)	80%
I Don't Know (%)	0.0%	I Don't Know (%)	20%

<u>Question 23:</u> How many weigh in Motion (WIM) sites in your state?

United States		**Canada**	
Mean	13.36	Mean	3
Range 0-8	54.5%	-	-
Range 9-37	45.5%	-	-
Minimum	0	Minimum	0
Maximum	37	Maximum	6

<u>Question 24:</u> How many Weigh in Motion (WIM) sites does your state use for mobile weight enforcement?

United States		**Canada**	
Mean	6		0
Range 0-3	50.0%		-
Range 4-27	50.0%		-
Minimum	0		0
Maximum	27		3

<u>Question 25:</u> What are the criteria for selecting the location for WIM for mobile weight enforcement?

Responses:

- Traffic volume, safe stop locations, bypass traffic volume.
- The ability to receive the data from the WIM to the patrol unit.
- Heavy routes not covered by fixed locations, seasonal traffic increases such as AG Harvest, other factors that affect traffic such as construction activities.
- Currently only WIM is at existing fixed facilities.
- Already established WIMs for traffic counts and a couple at border crossings.
- CMV traffic, bridge weight arrest, crash data, complaints.

<u>Question 26:</u> Does your state use Pre-Clearance Systems as a strategy for commercial vehicle enforcement?

United States		**Canada**	
No (%)	14.3%	No (%)	40%
Yes (%)	85.7%	Yes (%)	60%
I Don't Know (%)	0.0%	I Don't Know (%)	0%

<u>Question 27:</u> Which weigh station preclearance systems are used in your state?

United States			
PrePass		**NORPASS**	
No (%)	16.7%	No (%)	87.5%
Yes (%)	83.3%	Yes (%)	12.5%
I Don't Know (%)	0.0%	I Don't Know (%)	0.0%
Drivewyze		**Other**	
No (%)	55.6%	No (%)	100.0%
Yes (%)	44.4%	Yes (%)	0.0%
I Don't Know (%)	0.0%	I Don't Know (%)	0.0%

In Canada, New Brunswick said they used PrePass. British Columbia and Alberta said they used other preclearance systems.

<u>Question 28:</u> Please indicate the number of weigh stations using Pre-clearance systems indicated below.

United States			
PrePass		**NORPASS**	
Mean	8.88	Mean	1.30
Range 0-6	56.3%	Range 0	80.0%
Range 6-30	43.8%	Range 1-12	20.0%
Minimum	0	Minimum	0
Maximum	30	Maximum	12
Drivewyze		**Other**	
Mean	2.47	Mean	0
Range 0	46.7%	Range 0-8	0.0%
Range 1-8	53.3%	Range 9-37	0.0%
Minimum	0	Minimum	0
Maximum	8	Maximum	0

In Canada, most provinces are using other pre-clearance systems than the ones indicated above.

Question 29: **Does your state plan to continue using or expand your electronic pre-clearance systems?**

United States		Canada	
No (%)	5.9%	No (%)	0%
Yes (%)	94.1%	Yes (%)	100%
I Don't Know (%)	0.0%	I Don't Know (%)	0%

Question 30: **Which of the following pre-clearance system(s) does your state plan to continue using or expand?**

United States			
PrePass		**NORPASS**	
Continue	55.6%	Continue	7.1%
Expand	22.2%	Expand	7.1%
Not Continue or Expand	5.6%	Not Continue or Expand	21.4%
Not Applicable	16.7%	Not Applicable	64.3%
Drivewyze		**Other**	
Continue	5.9%	Continue	0.0%
Expand	29.4%	Expand	0.0%
Not Continue or Expand	23.5%	Not Continue or Expand	8.3%
Not Applicable	41.2%	Not Applicable	91.7%

In Canada, British Columbia and Alberta plan to continue using their other systems. New Brunswick plans to expand theirs.

Question 31: **Does your state use check-lane operations as a strategy for commercial vehicle enforcement in your state?**

United States		Canada	
No (%)	47.4%	No (%)	20%
Yes (%)	26.3%	Yes (%)	80%
I Don't Know (%)	26.3%	I Don't Know (%)	0%

Question 32: **What are the focuses of your Check-Lane Operations?**

United States					
Truck size and weight		**Safety and credentialing regulations**		**Other**	
No (%)	0.0%	No (%)	0.0%	No (%)	0.0%
Yes (%)	100.0%	Yes (%)	100.0%	Yes (%)	80.0%
I Don't Know (%)	0.0%	I Don't Know (%)	0.0%	I Don't Know (%)	20.0%

Question 33: **What are the criteria for selecting the location for Check-Lane Operations?**
Criteria:

- Usually our top 20 counties that involve CMV crashes.
- Use a high volume location of motor coaches and to achieve max results in a short time period.
- Traffic volume and safety.
- Type of operation and safety of inspection location.
- Volume and complaints.
- All CMV must enter site or use a uniform statistical selection process (every 10th CMV).
- Safe location for officers and truckers, high volume locations, bypass routes.
- Traffic patterns, available real estate to set up a safe zone.

Question 34: **Does your state use safe enforcement sites such as rest areas or roadway shoulders to perform enforcement of commercial vehicles?**

United States		**Canada**	
No (%)	10.5%	No (%)	0.0%
Yes (%)	89.5%	Yes (%)	100%
I Don't Know (%)	0.0%	I Don't Know (%)	0.0%

Question 35: **How many Safe Enforcement Sites with Pavement Cut-outs/notches in your state?**

United States	**Canada**
0 to 100 sites	**0 to 140 sites**

Question 36: **What are the criteria for selecting the location for Safe Enforcement Sites with Pavement Cut-outs/notches?**
Response:

Criteria:

- Routes not covered by fixed locations, highway safety, available right of way, Note: Montana does not utilize cutouts or notches.
- Partner with WSDOT to identify and construct safe roadside enforcement areas.
- Safety of the public and the Troopers.
- Traffic volume, direct site distance. Only used for inspection and/or weight.
- Site distance (Safety) and budget constraints.
- Visibility-ease of post inspection merge.
- Well-lit, wide shoulders, relationship with owners of rest stops.
- Distance apart, truck traffic, cost of installation, adjacent road work.
- Safe locations for officers and truckers, high volume locations, bypass routes.

<u>Question 37:</u> Does your state/province coordinate commercial vehicle enforcement operations with neighboring states?
Response:

United States		Canada
We Currently Coordinate	63.2%	80%
We are planning to coordinate	0.0%	0.0%
We do not coordinate	36.8%	20%

Reasons:

- Either via conference call or e-mail. We have participated in coordination with Operation Safe Driver in past years.
- Information sharing as well as occasional planned details on State borders.
- For specialized saturations we contact the neighboring state to identify the focus and to see if they we like to participate with us.
- We hold an annual meeting to decide the dates of approximately 3 to 4 details each year.
- We have joint agreements with two states and the providence of AB where officers either share facilities or are trained to do the work of the other jurisdictions.
- We have annual meetings for CMV enforcement including weight, inspection and specific targeted enforcement.
- Partner with surrounding state enforcement agencies to coordinate emphasis and share data/results.
- Monthly we have a conference call with all boarding states to go over current topics and to set up enforcement projects.
- Lining up enforcement campaigns at the same time, sharing information, scheduling common issues for focus.
- During Road Check we check CV going one direction and they will check CV going the other direction. Brake blitzes have been done with PEI and NS. Training has been done jointly among provinces.
- Joint Use Agreements with Montana, Saskatchewan and British Columbia. Share training.
- Some joint activities in border areas.

<u>Question 38:</u> Please provide (in the text box below) any additional information (e.g., new technologies employed) and comments about your commercial vehicle enforcement program.
Comments:

- The DPS units are not tasked with weight and permit enforcement. They are the state MCSAP lead agency and limit their activity to commercial vehicle safety inspection.

MDOT personnel conduct the safety inspections as well as weight, fuel tax, credential regulation.

- In addition to the new WIMS all of our enforcement personnel have sets of portable scales to use for weight enforcement. We also have a Civil Weight Program that we enforce as well as a Red Dye Fuel Program. For our mobile personnel, we are replacing civilian inspectors with troopers for the ability of increased probable cause stops. Civilian State Patrol Inspectors will continue to support MnDOT's fixed scale facilities.
- Added License Plate Readers and Infrared Technologies at our WIM/CVISN sites.
- We also use thermal imaging for brake inspections that are installed in mobile vans. We are planning to install a VWS on US Highway 64 near Ft. Smith in the near future.
- Recently employed LIDAR speed detection devices that possess video and photographic capabilities, as well as the capability of measuring the time and distance between two vehicles traveling in the same direction which will aid in the discovery and prosecution of tailgating infractions.
- Currently we focus on designated high crash areas based on the States crash reports. Driver behavior is the first reason for driver/vehicle selection.
- We are looking at 360 Smartview as a sorting tool at two of our larger scales.
- This year we began using Tru-Cam cameras/speed detectors on CMVs.
- Currently utilize Inspection program for electronic capture of vehicle inspections. Conduct yearly Enforcement Plan for Alberta.

9.2 Appendix 4.1. Annual Citation Fines at Enforcement Sites used for Checklane Operations

Enforcement Sites	2010	2011	2012	Annual Average	District
Dewitt Rest Area (I-127 S/B)	$25,000.00	$14,000.00	$20,000.00	$19,667.00	1
Holt Rest Area (US-127 N/B)	$43,000.00	$26,000.00	$3,000.00	$24,000.00	1
Belleville Rest Area (I-94 W/B)	$308,000.00	$22,000.00	$145,000.00	$158,333.00	2
Canton Rest Area (I-275 N/B)	-	$1,000.00	$24,000.00	$8,333.00	2
Chesterfield Safe Enforcement Site (I-94 E/B)	-	-	-	-	2
Chesterfield Safe Enforcement Site (I-94 W/B)	-	-	$8,000.00	$2,667.00	2
Clarkston Rest Area (I-75 S/B)	-	-	-	-	2
New Baltimore Safe Enforcement Site (I-94 E/B)	$2,000.00	$4,000.00	-	$2,000.00	2
New Baltimore Safe Enforcement Site (I-94 W/B)	$25,000.00	$66,000.00	-	$30,333.00	2
Pontiac Safe Enforcement Site (I-75 N/B)	-	-	$7,000.00	$2,333.00	2
360P1 - Ogemaw County Road Commission	$3,000.00	-	$1,000.00	$1,333.00	3
Adair Rest Area (I-94 E/B)	-	$1,000.00	$6,000.00	$2,333.00	3
Alger Rest Area (I-75 S/B)	$3,000.00	$19,000.00	$7,000.00	$9,667.00	3
Bay City Rest Area (I-75 S/B)	-	$11,000.00	$38,000.00	$16,333.00	3
Blue Water Bridge	$40,000.00	$65,000.00	$90,000.00	$65,000.00	3
Bridgeport Safe Enforcement Site (I-75 N/B)	$17,000.00	$16,000.00	-	$11,000.00	3
Capac Rest Area (I-69 W/B)	$66,000.00	$148,000.00	$161,000.00	$125,000.00	3
Clio Rest Area (I-75 S/B)	$54,000.00	$21,000.00	$58,000.00	$44,333.00	3
Dodge Road Rest Area (I-75 N/B)	$16,000.00	$9,000.00	-	$8,333.00	3
Fenton Rest Area (US-23 BR)	$27,000.00	$16,000.00	$20,000.00	$21,000.00	3
Five Lakes Rest Area	$43,000.00	$8,000.00	$8,000.00	$19,667.00	3
Linwood Rest Area (I-75 N/B)	$10,000.00	$31,000.00	$87,000.00	$42,667.00	3
M-13 Roadside Park	$2,000.00	-	-	$667.00	3
M-15 in Vassar	$2,000.00	$6,000.00	$9,000.00	$5,667.00	3
M-53 PITWS	-	$3,000.00	$3,000.00	$2,000.00	3
M-90 PITWS	$3,000.00	$2,000.00	$1,000.00	$2,000.00	3
Mayville Carpool Lot (M-24)	$7,000.00	-	-	$2,333.00	3
MDOT TSC (M-13 Connector)	$1,000.00	$2,000.00	$1,000.00	$1,333.00	3
New Baltimore Rest Area	$20,000.00	$4,000.00	-	$8,000.00	3
Swartz Creek Rest Area (I-69)	$24,000.00	$29,000.00	$22,000.00	$25,000.00	3
West Branch Carpool Lot	$1,000.00	-	-	$333.00	3
West Branch Rest Area (I-75 N/B	-	-	-	-	3
Woodbury Rest Area (I-69 W/B)	-	-	-	-	3
Alamo Rest Area (US-131 S/B)	$13,000.00	$9,000.00	$13,000.00	$11,667.00	5
Battle Creek Rest Area	$40,000.00	-	-	$13,333.00	5

Enforcement Sites	2010	2011	2012	Annual Average	District
Berrien County Road Commission	-	-	-	-	5
Bridgman Post	-	-	-	-	5
Coldwater Garage Training Facility (US-12)	-	$1,000.00	$4,000.00	$1,667.00	5
Coldwater Post	$1,000.00	$7,000.00	-	$2,667.00	5
Covert Rest Area (I-196 S/B)	$25,000.00	$10,000.00	$4,000.00	$13,000.00	5
Galesburg Rest Area (I-94 W/B)	$22,000.00	$6,000.00	$1,000.00	$9,667.00	5
Glenn Rest Area (I-196)	$1,000.00	$2,000.00	$2,000.00	$1,667.00	5
Hagar Township Detachment	-	-	-	-	5
Marshall Rest Area	$6,000.00	$1,000.00	-	$2,333.00	5
MDOT Niles Garage	-	-	-	-	5
Niles Rest Area (US-31 N/B)	$3,000.00	-	-	$1,000.00	5
Oshtemo Safe Enforcement Site	$27,000.00	$5,000.00	$11,000.00	$14,333.00	5
Paw Paw Post	$1,000.00	$1,000.00	-	$667.00	5
Sawyer Garage	-	-	-	-	5
Sugarloaf Safe Enforcement Site (US-131 N/B)	$2,000.00	$6,000.00	-	$2,667.00	5
Tekonsha Rest Area	$2,000.00	-	-	$667.00	5
Turkeyville Rest Area	$138,000.00	$70,000.00	$26,000.00	$78,000.00	5
Watervliet Rest Area (I-94 W/B)	$21,000.00	$3,000.00	$4,000.00	$9,333.00	5
White Pigeon Detachment	-	-	-	-	5
White Pigeon Post	$1,000.00	$5,000.00	-	$2,000.00	5
620R1 - Big Rapids Rest Area (US-131 S/B)	$4,000.00	$1,000.00	-	$1,667.00	6
Clare Rest Area (US-127)	$2,000.00	$3,000.00	-	$1,667.00	6
Fruitport Rest Area (I-96 W/B)	-	-	$1,000.00	$333.00	6
MDOT Garage (Reed City)	$14,000.00	$1,000.00	-	$5,000.00	6
Morley Rest Area (US-131 N/B)	$2,000.00	$1,000.00	$1,000.00	$1,333.00	6
Muskegon Rest Area (US-31 S/B)	$1,000.00	-	-	$333.00	6
Rockford Rest Area (US-131 S/B)	$1,000.00	-	$2,000.00	$1,000.00	6
Zeeland Rest Area (I-196 E/B)	$1,000.00	$1,000.00	$1,000.00	$1,000.00	6
M-57 SES	-	-	-	-	6
4 Mile Rest Area (I-75 N/B)	$6,000.00	$1,000.00	$8,000.00	$5,000.00	7
Alpena County Road Commission (US-23)	-	$1,000.00	-	$333.00	7
Alpena Post	$5,000.00	-	-	$1,667.00	7
Benzie County Road Commission (US-31)	-	-	$2,000.00	$667.00	7
Cadillac Post	-	-	-	-	7
Cadillac Rest Area (US-131 N/B)	-	$3,000.00	-	$1,000.00	7
Charlevoix County Road Commission (M-75) PITWS	-	-	-	-	7
DNR Trail Head Lot (US-131)	$1,000.00	$2,000.00	$2,000.00	$1,667.00	7
Emmet County Road Commission Garage	-	$1,000.00	-	$333.00	7

Enforcement Sites	2010	2011	2012	Annual Average	District
Fife Lake Roadside Park (US-131)	-	-	-	-	7
Frederic Rest Area on I-75 Southbound. Hartwick P.	-	$1,000.00	$4,000.00	$1,667.00	7
Gaylord Rest Area (I-75 N/B)	$1,000.00	-	-	$333.00	7
Hillman Roadside Park (M-32)	-	-	-	-	7
Houghton Lake Post	-	$1,000.00	-	$333.00	7
Kalkaska MDOT Garage	$15,000.00	$3,000.00	-	$6,000.00	7
MDOT Garage (Atlanta)	-	-	$1,000.00	$333.00	7
Missaukee County Road Commission Garage	$12,000.00	-	$1,000.00	$4,333.00	7
Oscoda County Road Commision Garage	-	-	-	-	7
Otsego County Road Commission (I-75 BR)	$24,000.00	$46,000.00	$16,000.00	$28,667.00	7
Presque Isle County Road Commission Garage	-	-	-	-	7
Roscommon County Carpool Lot (CR-104)	-	$9,000.00	$1,000.00	$3,333.00	7
Roscommon County Road Commission Garage	$29,000.00	$42,000.00	$16,000.00	$29,000.00	7
Snowbowl Rest Area (US-127 N/B)	$2,000.00	$2,000.00	-	$1,333.00	7
Topinabee Rest Area (I-75 N/B)	-	-	-	-	7
Traverse City Post	-	-	-	-	7
Vanderbilt Rest Area (I-75 S/B)	$2,000.00	$8,000.00	$9,000.00	$6,333.00	7
Wexford County Road Commission Garage	$14,000.00	$2,000.00	$1,000.00	$5,667.00	7
8th District HQ	-	-	$2,000.00	$667.00	8
CR-426/CR-420 PITWS	$2,000.00	-	$2,000.00	$1,333.00	8
International Bridge	$20,000.00	-	$5,000.00	$8,333.00	8
Iron River Post	$1,000.00	-	-	$333.00	8
M-117 1.5 Miles North of US-2 @ Engadine	-	$5,000.00	-	$1,667.00	8
M-28 PITWS (Eckerman)	$2,000.00	$1,000.00	$3,000.00	$2,000.00	8
M-28 Seney Rest Area	-	-	$3,000.00	$1,000.00	8
M-553 @ County Road 480, Marquette County	$8,000.00	$19,000.00	$7,000.00	$11,333.00	8
M-69 PITWS (Randville)	$47,000.00	$24,000.00	$31,000.00	$34,000.00	8
M-69 Westside of County Road 551	$4,000.00	-	-	$1,333.00	8
Mackinac Bridge	$19,000.00	$7,000.00	$10,000.00	$12,000.00	8
Manistique Post	$1,000.00	$2,000.00	-	$1,000.00	8
Menominee PD Detachment	-	-	$2,000.00	$667.00	8
Negaunee Post	$3,000.00	-	-	$1,000.00	8
Sault St. Marie Post	$2,000.00	$4,000.00	-	$2,000.00	8
St. Ignace Post	$2,000.00	-	-	$667.00	8
US-2 @ Schoolcraft / Mackinac County Line	$2,000.00	-	-	$667.00	8
US-2 Bessemer PITWS	-	-	$6,000.00	$2,000.00	8
US-2 Cut River Bridge rest Area	-	-	$4,000.00	$1,333.00	8

Enforcement Sites	2010	2011	2012	Annual Average	District
US-2 West of Hog Island Creek. Naubinway Rest Area	-	-	$2,000.00	$667.00	8
US-2/M-95 PITWS	$22,000.00	$11,000.00	$12,000.00	$15,000.00	8
US-2/US-41 Junction PITWS	$16,000.00	$29,000.00	$7,000.00	$17,333.00	8
US-41 PITWS	$27,000.00	$4,000.00	-	$10,333.00	8
Wakefield Post	-	$2,000.00	-	$667.00	8
TOTAL	**$1,359,000.00**	**$887,000.00**	**$946,000.00**	**$1,063,998.00**	

9.3 Appendix 4.2. Citation Fines at Other Enforcement Sites

Enforcement Sites	2010	2011	2012	Annual Average
(CR-553/CR-551) PITWS	$1,000.00	-	-	$333.00
410 - Mt. Pleasant Post	-	-	-	-
Adrian Post	$9,000.00	$3,000.00	-	$4,000.00
Alma Rest Area (US-127 N/B)	-	-	-	-
Ambassador Bridge	$4,000.00	-	-	$1,333.00
Auburn Hills Detachment	$2,000.00	$1,000.00	$4,000.00	$2,333.00
*Battle Creek Post	$40,000.00	$16,000.00	-	$18,667.00
Berry Road Rest Area (US-127 S/B)	$16,000.00	$11,000.00	$6,000.00	$11,000.00
*Birch Run Safe Enforcement Site (I-75 N/B)	-	-	$24,000.00	$8,000.00
*Bridgeport Post	-	-	-	-
Brighton Post	$2,000.00	-	-	$667.00
*Caro Post	-	-	-	-
*Cheboygan Post	-	-	-	-
Chesterfield Township Detachment	-	-	-	-
Coldwater Welcome Center	$6,000.00	-	$4,000.00	$3,333.00
Coloma Garage	$1,000.00	-	-	$333.00
*Coloma Rest Area (I-94 E/B)	-	-	-	-
*Corunna Post	$49,000.00	$32,000.00	-	$27,000.00
County Garage (1 Mile Road)	-	-	-	-
County Garage (Jordon Lake Road)	-	-	-	-
County Garage (M-20)	$4,000.00	$3,000.00	$1,000.00	$2,667.00
County Garage (US-131)	-	-	-	-
Davidsburg Rest Area (I-75 N/B)	-	-	-	-
Detroit Freeway Post	$8,000.00	$7,000.00	-	$5,000.00
Dundee Rest Area (US-23 N/B)	$325,000.00	$202,000.00	$29,000.00	$185,333.00
Dundee Township Detachment	-	-	$12,000.00	$4,000.00
*Felch Safe Enforcement Site (M-69)	$2,000.00	-	-	$667.00
*Flint Post	$10,000.00	$9,000.00	$21,000.00	$13,333.00
Gladstone Post	-	-	-	-
Grand Haven Detachment	-	-	$6,000.00	$2,000.00
Grand Haven Post	$10,000.00	$1,000.00	-	$3,667.00
Grand Ledge Rest Area (I-96 E/B)	-	-	$2,000.00	$667.00
Grass Lake Rest Area (I-94 W/B)	-	-	$1,000.00	$333.00
Green Oaks PD (US-23)	$24,000.00	$20,000.00	$5,000.00	$16,333.00
Groveland Detachment	-	-	-	-

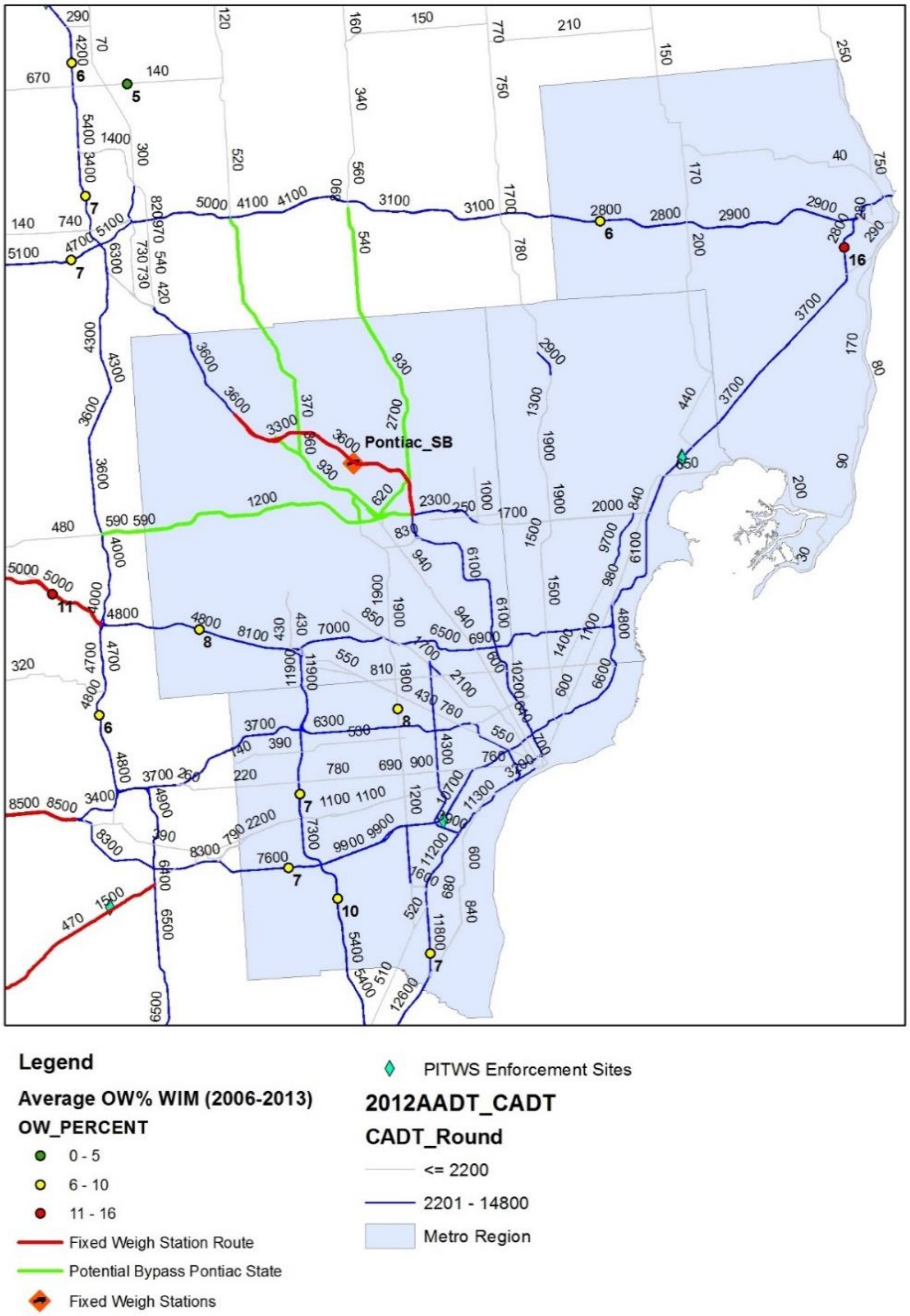
Enforcement Sites	2010	2011	2012	Annual Average
Hamtramck PITWS	$5,000.00	$15,000.00	-	$6,667.00
Holly Rest Area (I-75 N/B)	-	-	-	-
Howell Rest Area (I-96 E/B)	-	-	$3,000.00	$1,000.00
Ionia Detachment	-	-	$43,000.00	$14,333.00
Ionia Post	$41,000.00	$31,000.00	-	$24,000.00
Ithaca Post	$12,000.00	$4,000.00	-	$5,333.00
Jackson County Road Commission (M-106)	-	-	-	-
Jackson Post	$19,000.00	$4,000.00	$2,000.00	$8,333.00
Jefferson Rd Enforcement Site	$7,000.00	$4,000.00	$34,000.00	$15,000.00
Jonesville Post	-	-	-	-
Kalamazoo Garage	-	-	-	-
*Kalkaska Post	-	-	-	-
*Keweenaw Sheriff Dept. Remote Office	-	-	-	-
*Lake Antoine Boat Launch Lot	-	-	-	-
Lake Chemung Rest Area (I-96 W/B)	$2,000.00	$1,000.00	$1,000.00	$1,333.00
Lakeview Post	-	-	-	-
Lansing Post	$1,000.00	$1,000.00	$2,000.00	$1,333.00
Lansing Road (SOS/IRP Lot)	$11,000.00	$8,000.00	$8,000.00	$9,000.00
*Lapeer Post	-	-	-	-
M-102 PITWS (Ferndale)	-	$1,000.00	$3,000.00	$1,333.00
M-21 Safe Enforcement Site	-	-	$3,000.00	$1,000.00
*M-35 @ Cedar River	$1,000.00	-	-	$333.00
M-51 PITWS	$3,000.00	-	-	$1,000.00
*M-61 Carpool Lot	-	-	-	-
M-82 Roadside Park	$6,000.00	$10,000.00	-	$5,333.00
MDOT Garage (I96 @ US23)	-	-	$3,000.00	$1,000.00
Metro North Post	$1,000.00	-	-	$333.00
Monroe Inspection Building	$52,000.00	$18,000.00	$102,000.00	$57,333.00
Monroe Post	-	$9,000.00	$19,000.00	$9,333.00
Mt. Pleasant Post	-	-	-	-
Niles Post	-	-	-	-
Northfield Church Rest Area (US-23 S/B)	$3,000.00	$24,000.00	$37,000.00	$21,333.00
Okemos Rest Area (I-96 W/B)	-	$10,000.00	-	$3,333.00
Park and Ride (US23 @ M59)	-	-	$1,000.00	$333.00
Plainwell Detachment	-	-	-	-
Plainwell Garage	-	-	-	-
*Port Huron PD Detachment	-	-	$1,000.00	$333.00

Enforcement Sites	2010	2011	2012	Annual Average
Portland Rest Area (I-96 W/B)	-	-	$1,000.00	$333.00
Potterville Rest Area (I-69 E/B)	$6,000.00	$27,000.00	$78,000.00	$37,000.00
Reed City Detachment	-	-	$14,000.00	$4,667.00
Reed City Post	$10,000.00	$13,000.00	-	$7,667.00
Residence	-	-	-	-
*Richmond Post	$16,000.00	$4,000.00	-	$6,667.00
Rockford Post	$50,000.00	$54,000.00	$45,000.00	$49,667.00
*Rogers City Detachment	-	-	-	-
Royal Oak. WB I-696 Service Drive. E. of Woodward	$8,000.00	$2,000.00	$2,000.00	$4,000.00
Sandstone Rest Area (I-94 E/B)	-	$1,000.00	$5,000.00	$2,000.00
Saranac Rest Area (I-96 E/B)	$2,000.00	$1,000.00	-	$1,000.00
Saugatuck Rest Area (I-96 W/B)	$3,000.00	-	-	$1,000.00
Sheridan Detachmen	-	-	-	-
South Haven Garage	-	-	$2,000.00	$667.00
South Haven Rest Area (I-196)	$5,000.00	$2,000.00	$2,000.00	$3,000.00
Springfield PDS Detachment	-	-	$1,000.00	$333.00
*Stephenson Post	$5,000.00	-	-	$1,667.00
*Tri City Post	-	-	$7,000.00	$2,333.00
Troy D.P.W. Yard. Rochester Rd.S. of 18 Mile Rd.	-	-	$24,000.00	$8,000.00
Tustin Rest Area (US-131 S/B)	$1,000.00	$1,000.00	-	$667.00
US-12 PITWS	$19,000.00	$14,000.00	$16,000.00	$16,333.00
US-127/M-21 Park N Ride	$3,000.00	$8,000.00	-	$3,667.00
US-127/M-57	$1,000.00	$2,000.00	-	$1,000.00
US-127/Price Road	$1,000.00	-	-	$333.00
*US-2 @ County Road 186, Rapid River	-	-	$4,000.00	$1,333.00
US-223 PITWS	$12,000.00	$67,000.00	$127,000.00	$68,667.00
Walker Road Rest Area (I-96 E/B)	-	-	$1,000.00	$333.00
*West Branch Post	-	-	$1,000.00	$333.00
*White Pigeon Roadside Park (US-12)	$18,000.00	$9,000.00	$4,000.00	$10,333.00
Ypsilanti Post	-	-	-	-
Mackinaw City Welcome Center	-	-	-	-
Antrim County Road Commission garage	-	-	-	-
Other	$1,292,000.00	$864,000.00	$1,071,000.00	$1,075,667.00
Totals	**$2,129,000.00**	**$1,514,000.00**	**$1,782,000.00**	**$1,808,328.00**

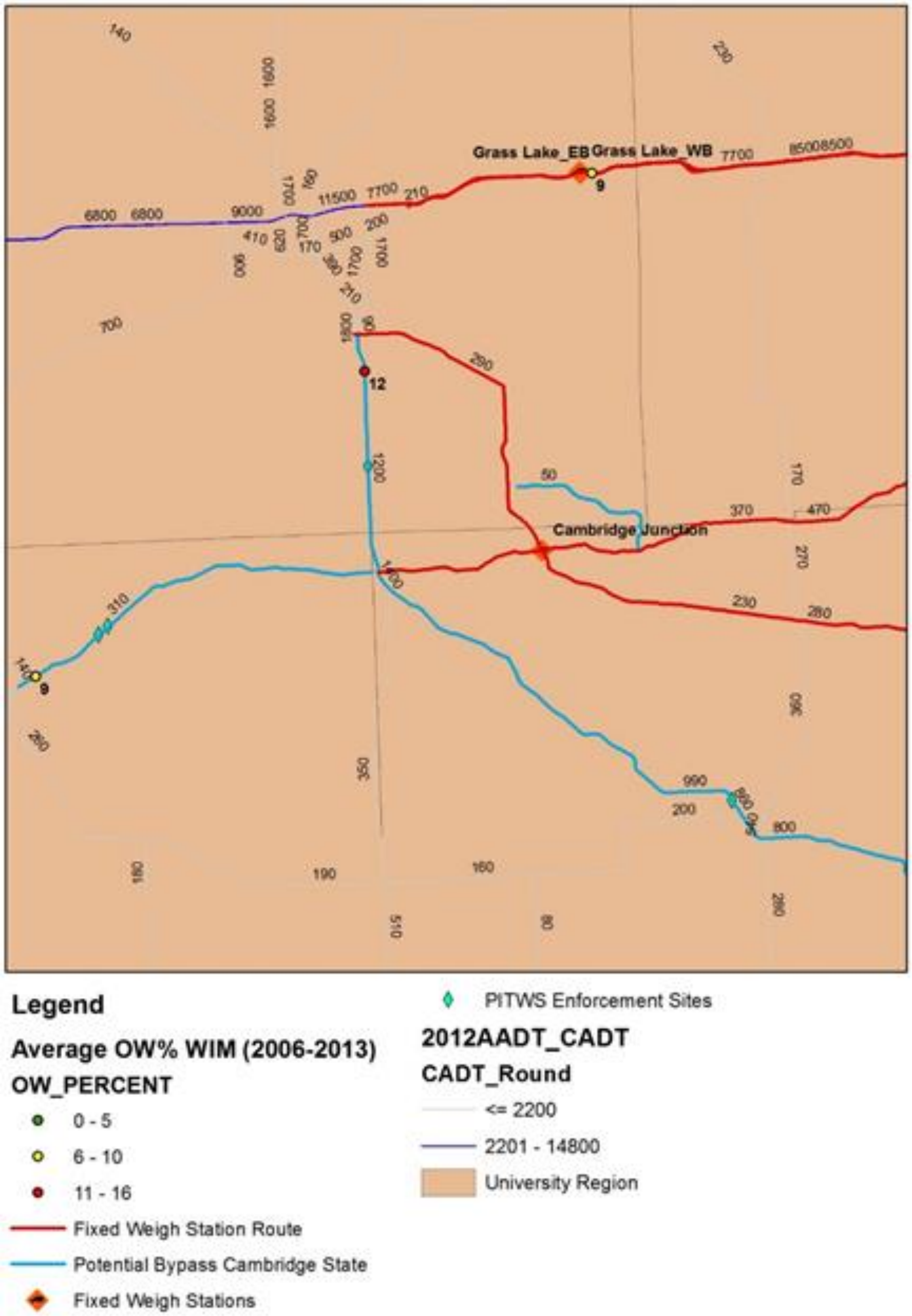
*These sites may not be usable

9.4 Appendix 4.2. Potential Bypass Routes Maps

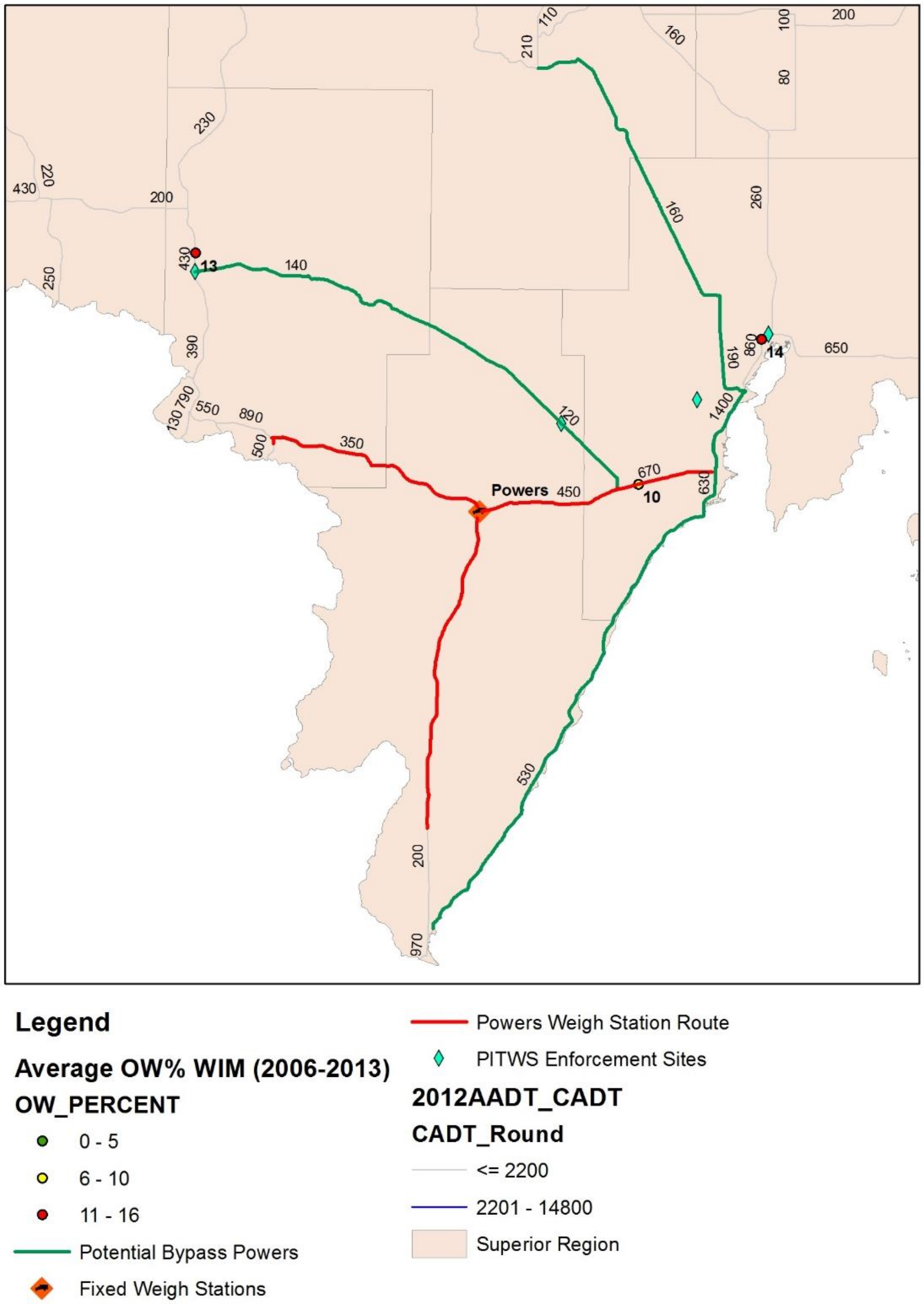
Pontiac SB Fixed Weigh Station



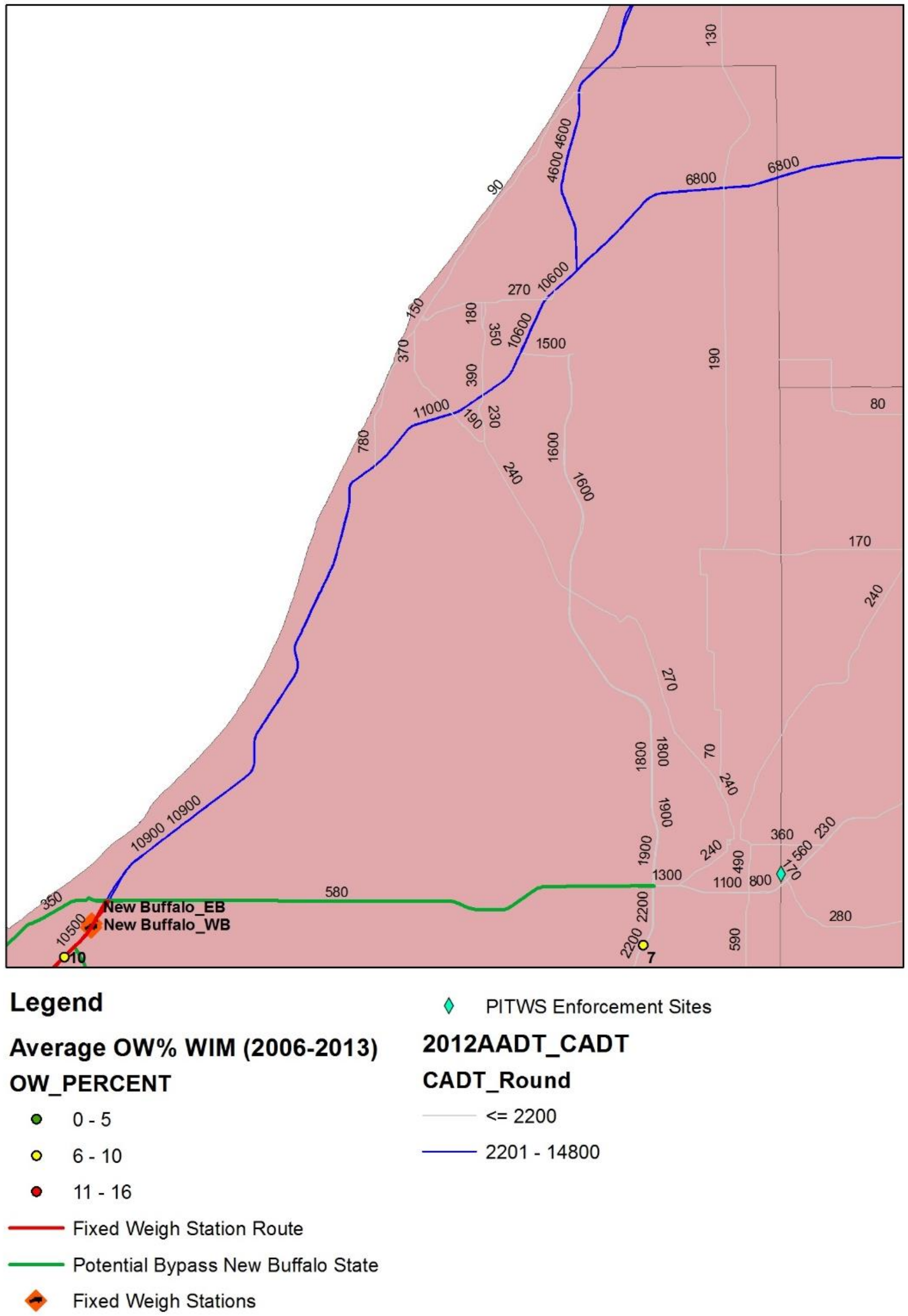
Cambridge Fixed Weigh Station



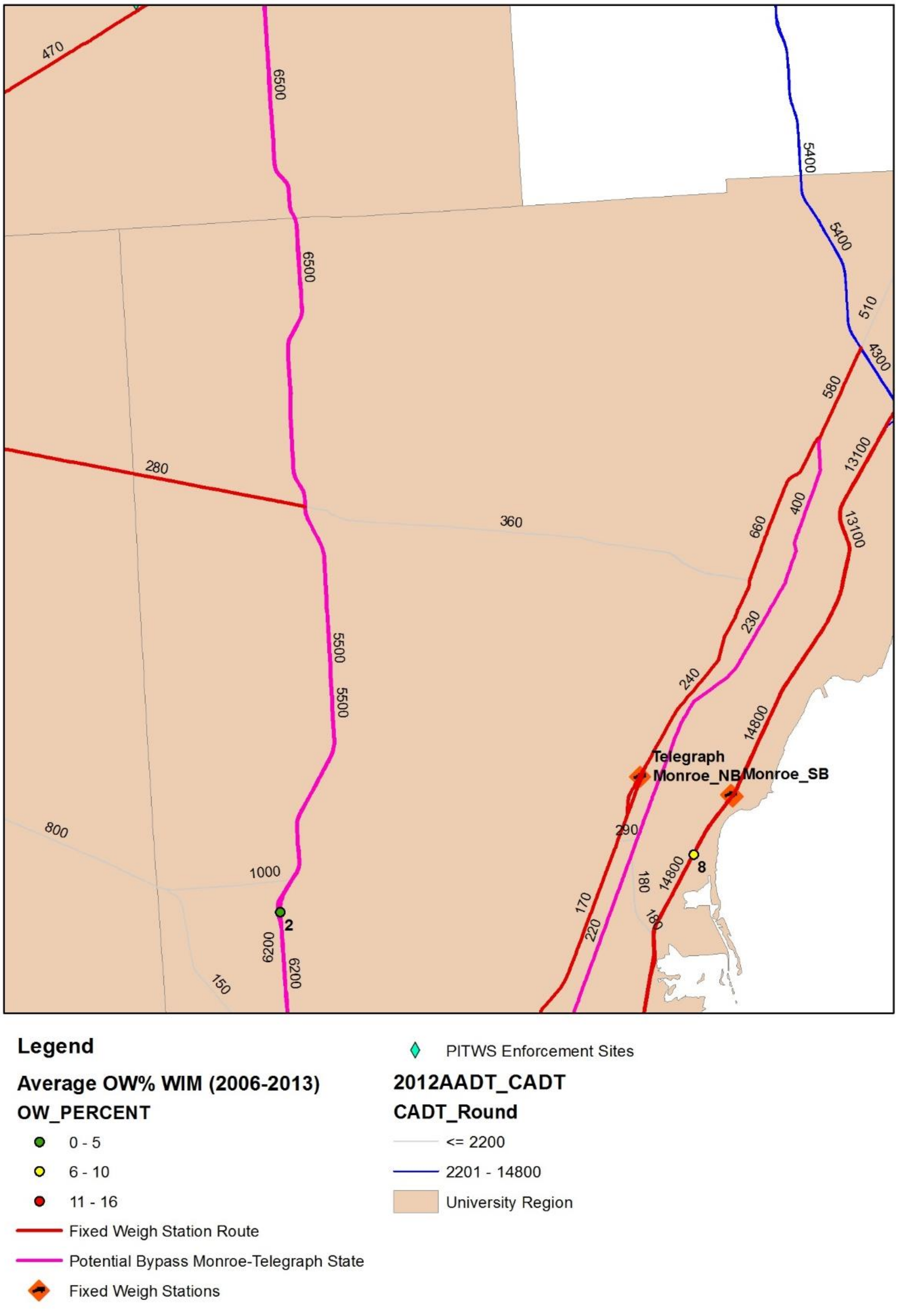
Powers Fixed Weigh Station



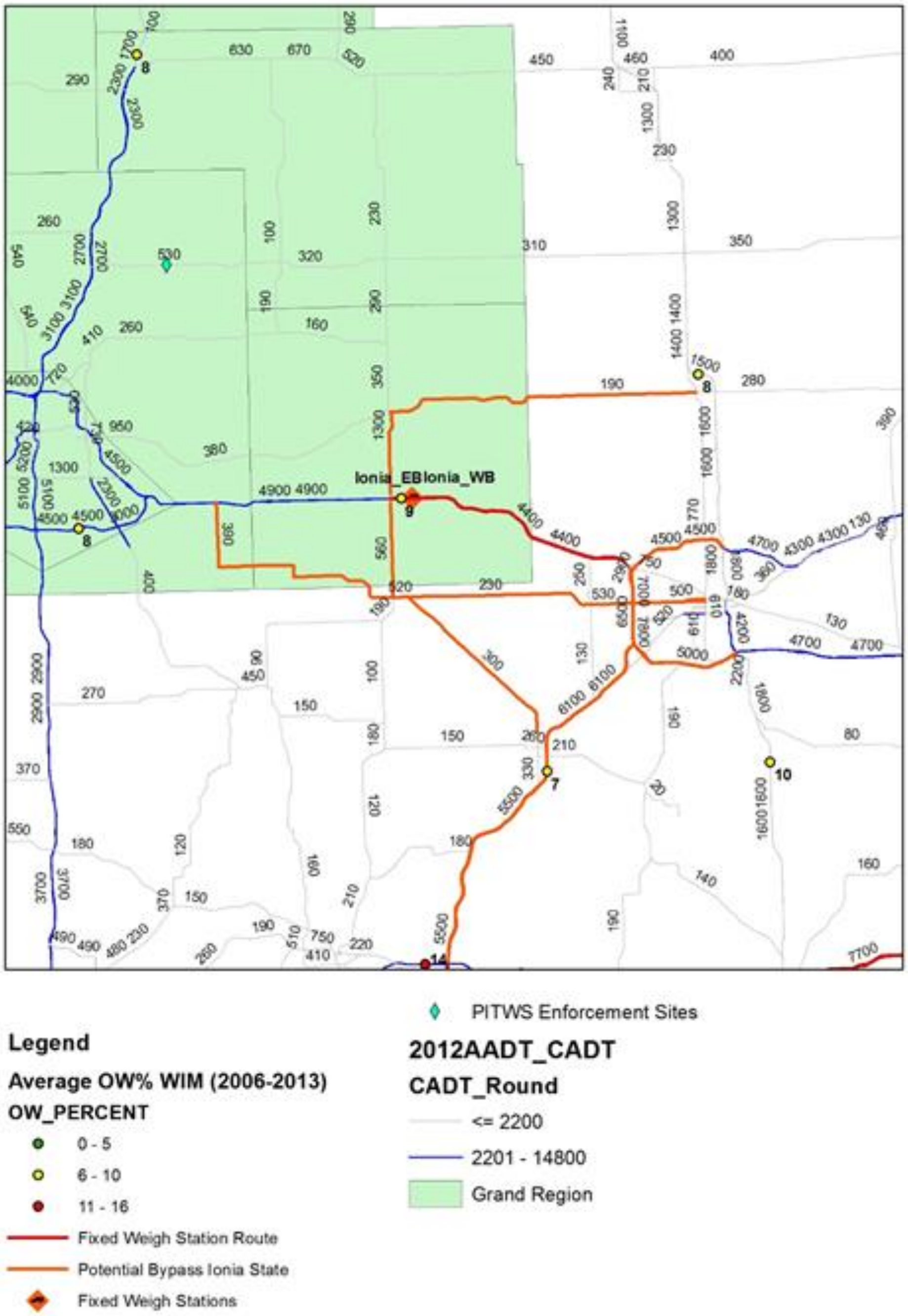
New Buffalo Fixed weigh Stations



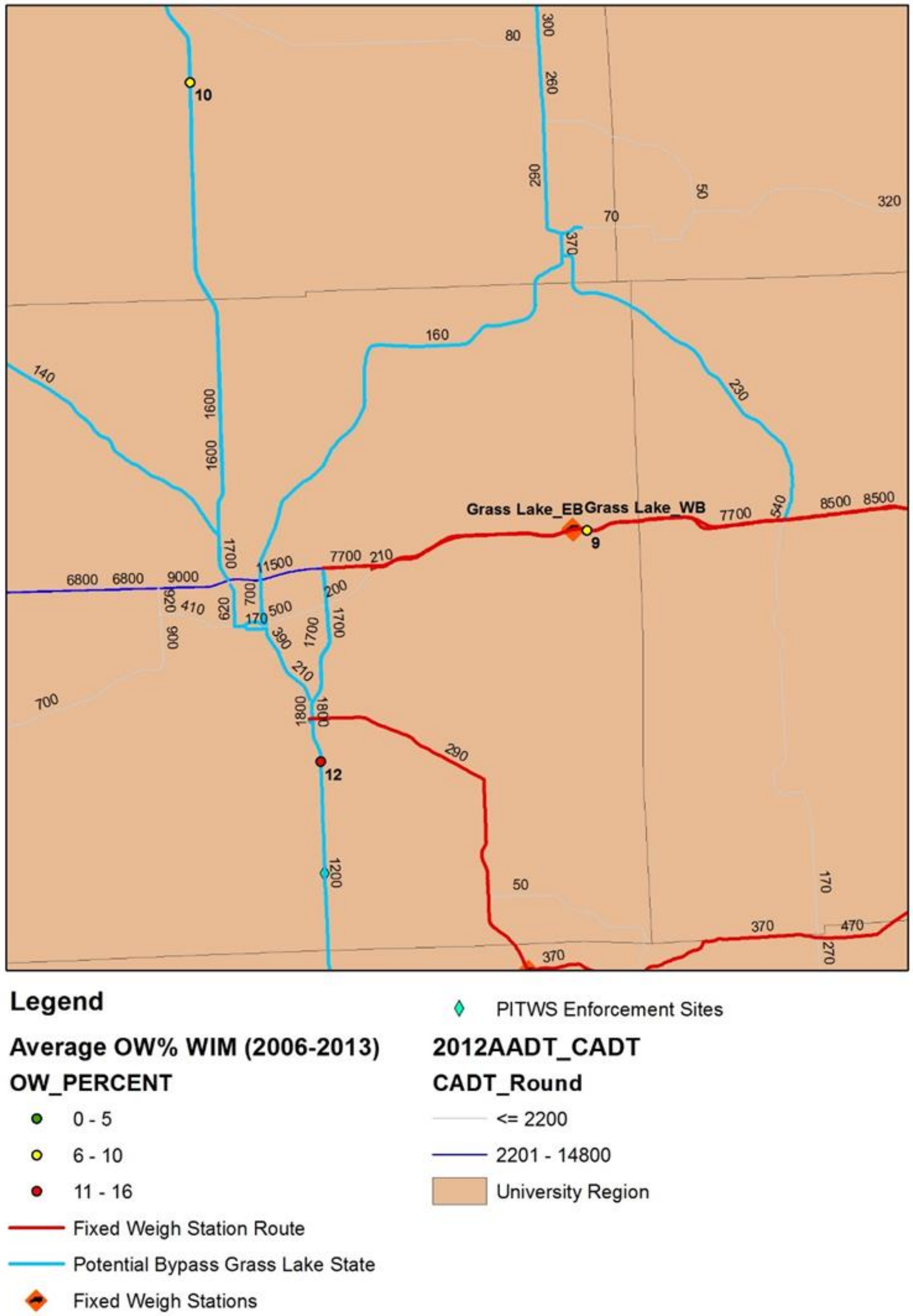
Telegraph and Monroe Fixed Weigh Stations



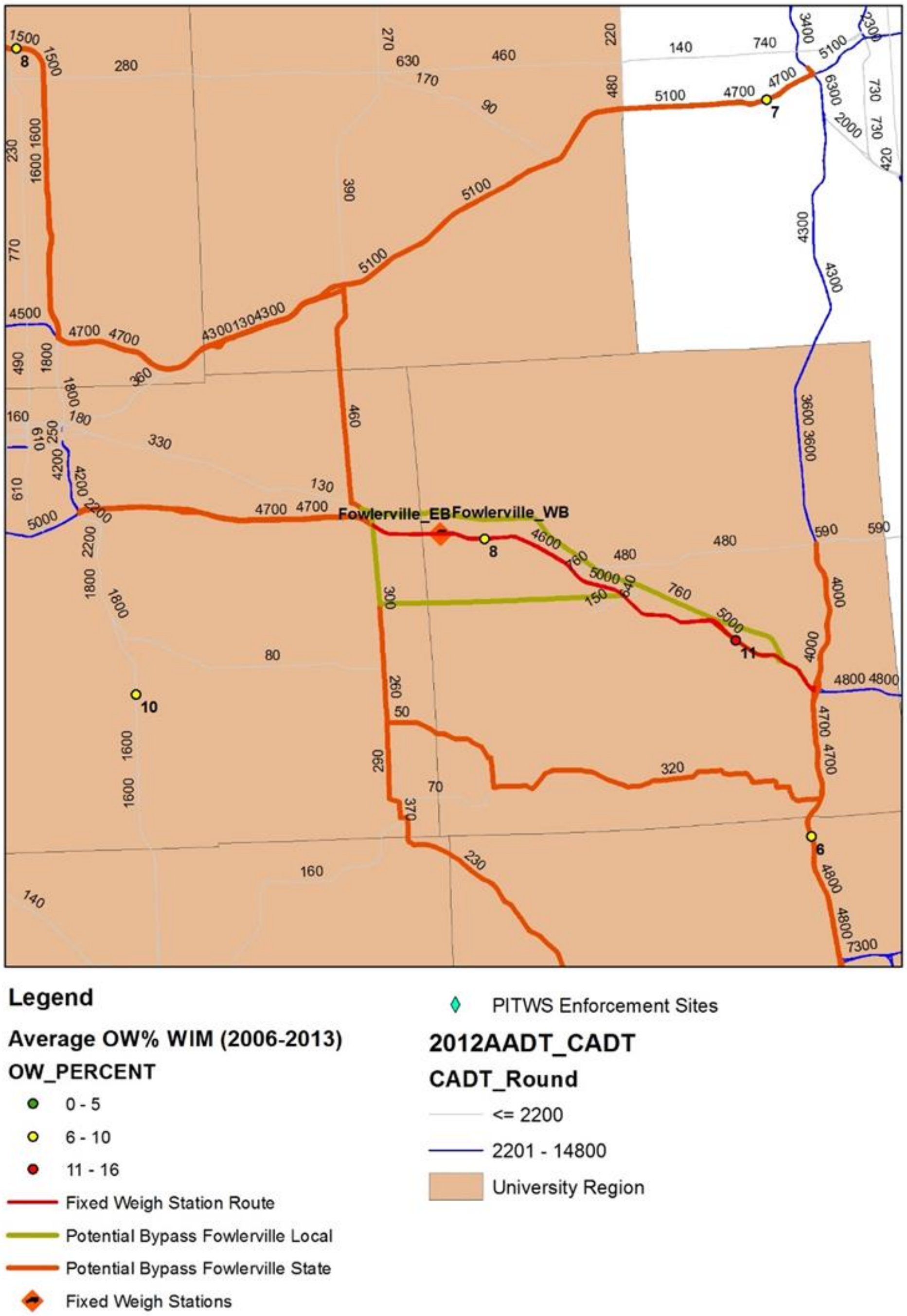
Ionia Fixed Weigh Stations



Grass Lake Fixed Weigh Stations

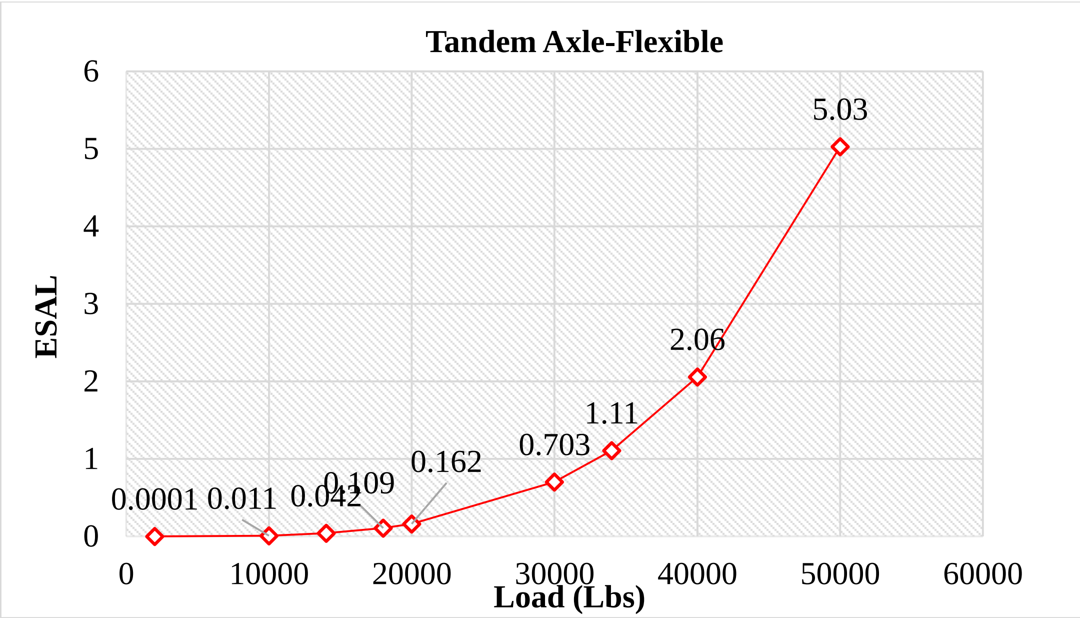


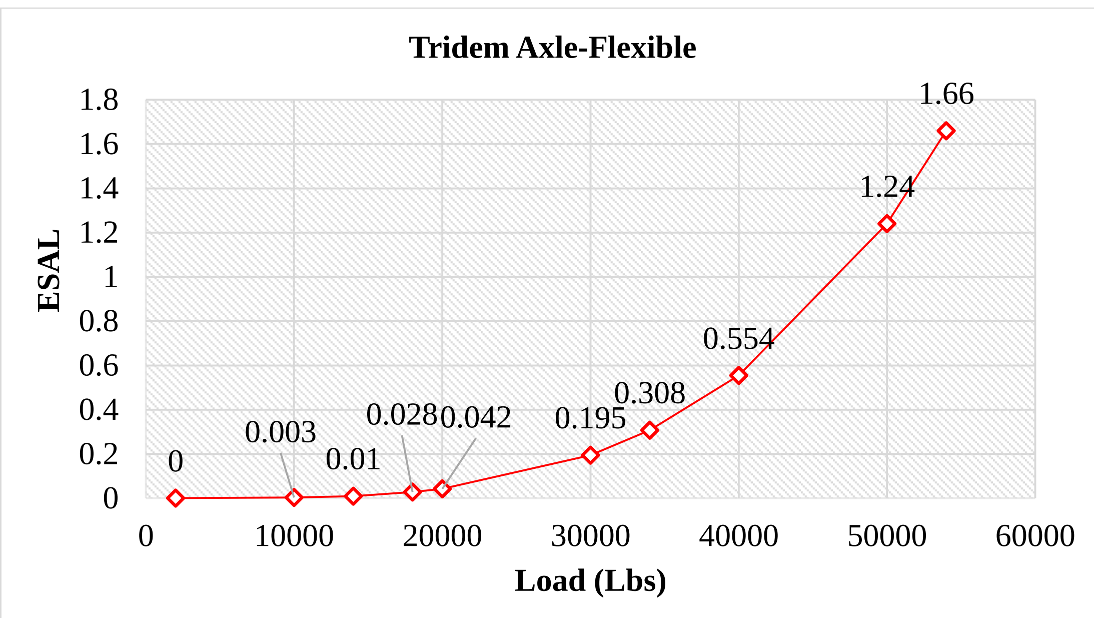
Fowlerville Fixed Weigh Stations

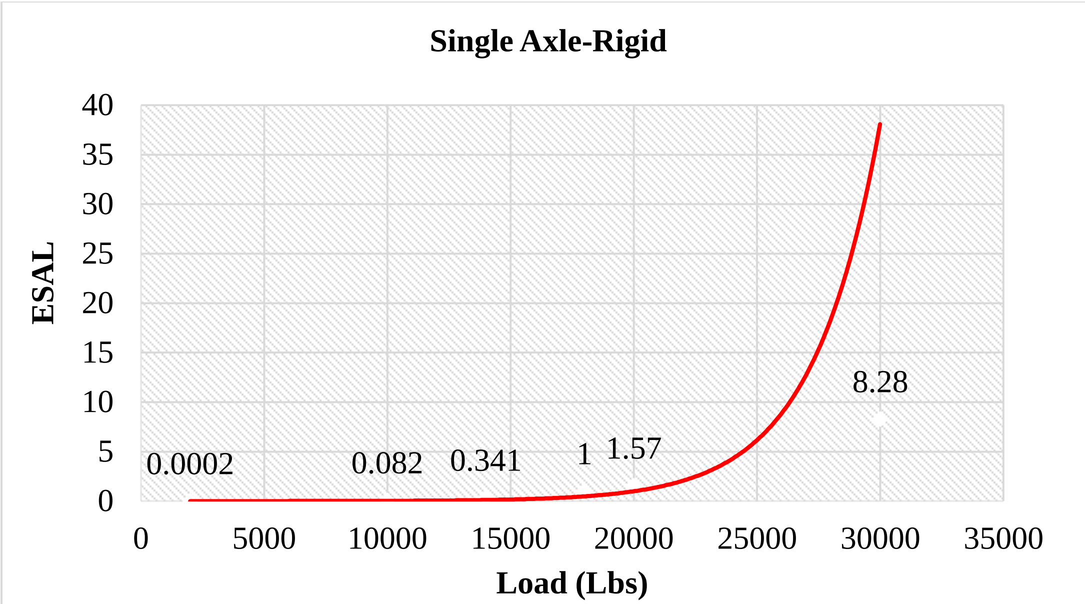


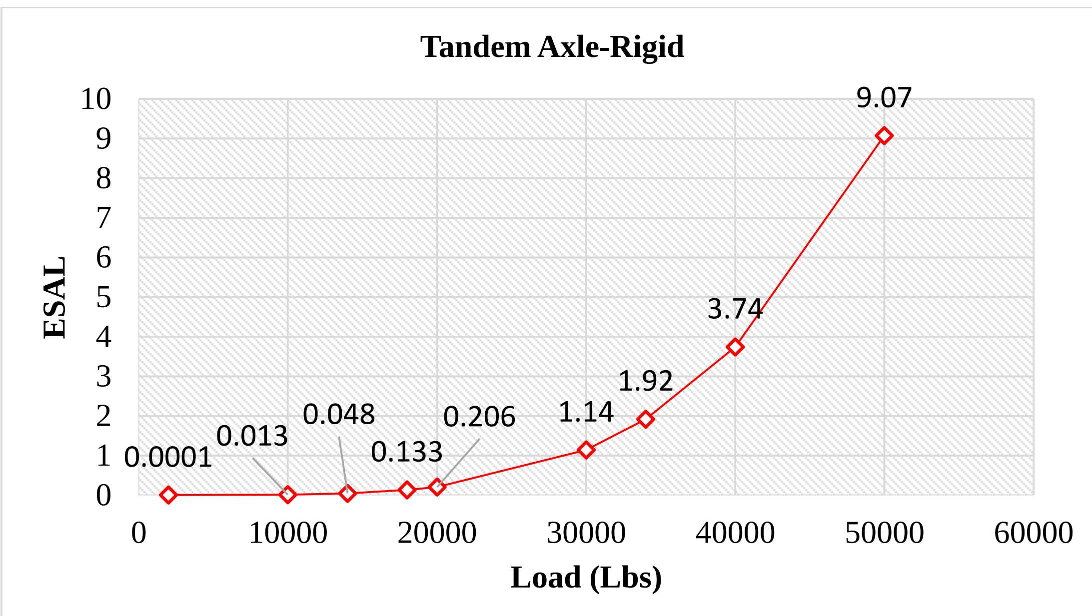
Coldwater Fixed Weigh Station

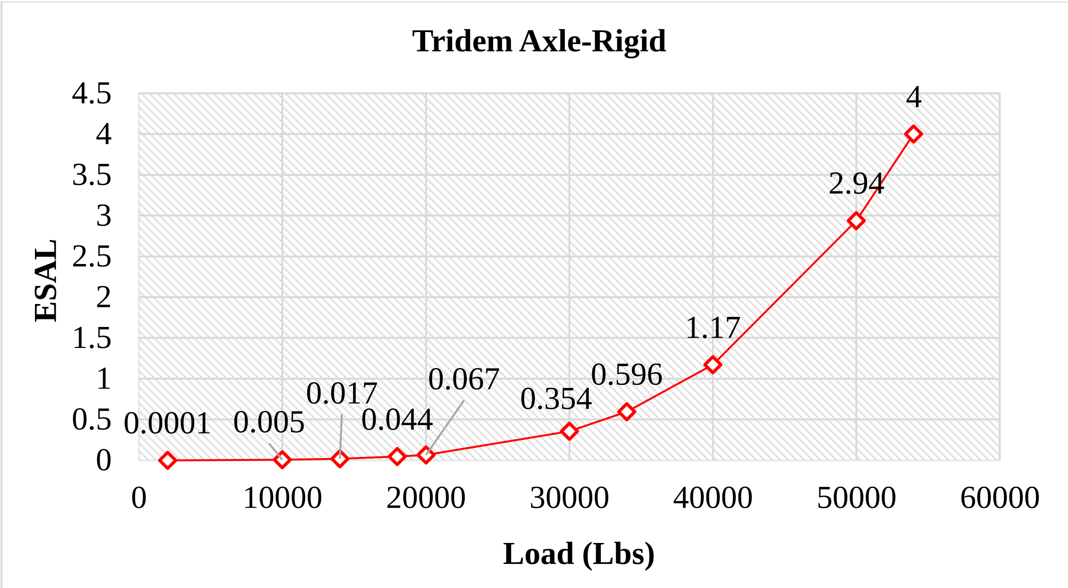
9.5 Appendix 5.1. ESAL Graphs






Single Axle-Rigid
ESAL
Load (Lbs)
0
5
10
15
20
25
30
35
40
0
5000
10000
15000
20000
25000
30000
35000
0.0002
0.082
0.341
1
1.57
8.28


Tandem Axle-Rigid
ESAL
Load (Lbs)
0
1
2
3
4
5
6
7
8
9
10
0
10000
20000
30000
40000
50000
60000
0.0001
0.013
0.048
0.133
0.206
1.14
1.92
3.74
9.07


Tridem Axle-Rigid
ESAL
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.0001
0.005
0.017
0.044
0.067
0.354
0.596
1.17
2.94
4
0
10000
20000
30000
40000
50000
60000
Load (Lbs)

9.6 Appendix 5.2. Unit Loading

Unit Loading for Flexible Pavement

No. of Axles	Truck Configuration	ESAL	Proportions	Weighted Average
2 Axles	1S+1S	2	1	2
3 Axles	1S+1T	1.54	0.9	1.686
	1S+1S+1S	3	0.1	
4 Axles	1S+1S+1T	2.32	0.9	2.369
	1S+1T+1S	2.81	0.1	
5 Axles	1S+1T+1T	2.08	0.8	2.445
	1S+1T+1S+1S	3.54	0.15	
	1S+1S+1S+1S+1S	5	0.05	
6 Axles	1S+1T+1T+1S	1.86	0.2	3.1115
	1S+1T+1S+1S+1S	4.54	0.45	
	1S+1T+1TR	1.99	0.35	
7 Axles	1S+1T+2T	2.45	0.9	2.5905
	1S+1T+1S+1S+1S+1S	5.81	0.05	
	1S+1TR+1TR	1.9	0.05	
8 Axles	1S+1T+1S+1TR+1S	4.26	0.65	3.9765
	1+1T+1S+2T	3.45	0.35	
9 Axles	1S+1T+1S+2T+1S	4.18	0.7	4.4515
	1S+1T+1S+1T+1TR	3.31	0.05	
	1S+1T+1S+1TR+1S+1S	5.44	0.25	
10 Axles	1S+1T+1S+1TR+1TR	3.71	0.7	3.971
	1S+1T+1T+TR+1S+1S	4.58	0.3	
11 Axles	1S+1T+1S+2T+1TR	3.63	0.5	3.477
	1S+1T+4T	2.82	0.35	
	1S+1T+1S+2T+1S+1T	4.5	0.15	
S= Single Axle; T= Tandem Axle; TR= Tridem Axle				

Overweight Unit Loading for Flexible Pavement

No. of Axles	Truck Configuration	ESAL	Proportions	Weighted Average
2	1S+1S	2.78	1	2.78
3	1S+1T	2.12	0.9	2.253
	1S+1S+1S	3.45	0.1	
4	1S+1S+1T	5.17	0.1	2.783
	1S+1T+1S	3.59	0.4	
	1S+1TR	1.66	0.5	
5	1S+1T+1T	2.69	0.95	2.763
	1S+1T+1S+1S	4.15	0.05	
6	1S+1T+1T+1S	2.91	0.05	3.794
	1S+1T+1S+1S+1S	4.69	0.65	
	1S+1T+1TR	2	0.3	
7	1S+1T+2T	2.85	0.4	3.88
	1S+1T+1S+1S+1S+1S	5.84	0.4	
	1S+1TR+1TR	2.02	0.2	
8	1S+1T+1S+1TR+1S	4.8	0.55	4.6785
	1+1T+1S+2T	4.53	0.45	
9	1S+1T+1S+2T+1S	5.32	0.6	4.999
	1S+1T+1S+1T+1TR	3.97	0.25	
	1S+1T+1S+1TR+1S+1S	5.43	0.15	
10	1S+1T+1S+1TR+1TR	4.19	0.7	4.355
	1S+1T+1T+TR+1S+1S	4.74	0.3	
11	1S+1T+1S+1TR+2T	4.29	0.65	3.9415
	1S+1T+4T	3.16	0.25	
	1S+1T+1S+2T+1S+1T	3.63	0.1	
S= Single Axle; T= Tandem Axle; TR= Tridem Axle				

Unit Loading for Rigid Pavement

No. of Axles	Truck Configuration	ESAL	Proportions	Weighted Average
2	1S+1S	2	1	2
3	1S+1T	1.48	0.9	1.632
	1S+1S+1S	3	0.1	
4	1S+1S+1T	2.43	0.9	2.519
	1S+1T+1S	3.32	0.1	
5	1S+1T+1T	1.96	0.8	2.34
	1S+1T+1S+1S	3.48	0.15	
	1S+1S+1S+1S+1S	5	0.05	
6	1S+1T+1T+1S	1.91	0.2	3.231
	1S+1T+1S+1S+1S	4.48	0.45	
	1S+1T+1TR	2.38	0.35	
7	1S+1T+2T	2.34	0.9	2.497
	1S+1T+1S+1S+1S+1S	2.34	0.05	
	1S+1TR+1TR	5.48	0.05	
8	1S+1T+1S+1TR+1S	4.38	0.65	4.016
	1+1T+1S+2T	3.34	0.35	
9	1S+1T+1S+2T+1S	4.34	0.7	4.5735
	1S+1T+1S+1T+1TR	3.81	0.05	
	1S+1T+1S+1TR+1S+1S	5.38	0.25	
10	1S+1T+1S+1TR+1TR	4.28	0.7	4.439
	1S+1T+1T+TR+1S+1S	4.81	0.3	
11	1S+1T+1S+2T+1TR	4.24	0.5	3.9555
	1S+1T+4T	3.2	0.35	
	1S+1T+1S+2T+1S+1T	4.77	0.15	
S= Single Axle; T= Tandem Axle; TR= Tridem Axle				

Overweight Unit Loading for Rigid Pavements

No. of Axles	Truck Configuration	ESAL	Proportions	Weighted Average
2	1S+1S	3.1	1	3.1
3	1S+1T	2.94	0.9	3.014
	1S+1S+1S	3.68	0.1	
4	1S+1S+1T	5.64	0.1	3.71
	1S+1T+1S	4.84	0.4	
	1S+1TR	2.42	0.5	
5	1S+1T+1T	3.77	0.95	3.831
	1S+1T+1S+1S	4.99	0.05	
6	1S+1T+1T+1S	2.98	0.05	3.888
	1S+1T+1S+1S+1S	4.64	0.65	
	1S+1T+1TR	2.41	0.3	
7	1S+1T+2T	3.98	0.4	4.768
	1S+1T+1S+1S+1S+1S	6.38	0.4	
	1S+1TR+1TR	3.12	0.2	
8	1S+1T+1S+1TR+1S	6.17	0.55	5.864
	1+1T+1S+2T	5.49	0.45	
9	1S+1T+1S+2T+1S	6.43	0.6	6.112
	1S+1T+1S+1T+1TR	5.05	0.25	
	1S+1T+1S+1TR+1S+1S	6.61	0.15	
10	1S+1T+1S+1TR+1TR	4.35	0.7	4.596
	1S+1T+1T+TR+1S+1S	5.17	0.3	
11	1S+1T+1S+1TR+2T	5.74	0.65	5.24
	1S+1T+4T	4.16	0.25	
	1S+1T+1S+2T+1S+1T	4.69	0.1	
S= Single Axle; T= Tandem Axle; TR= Tridem Axle				

9.7 Appendix 5.3. Computation of Net safety Impact of Fixed Weigh Stations

Weigh Station	(2004-2011)- Before Facility 3000-5280 ft.				(2004-2011)- Crashes at Facility			Actual Number of Crashes	Average Crashes /year	Proportion of Hours of Operation	Net Average Crashes /year
	CMV Crashes	All Vehicle Crashes	Attributed to FWS	Crashes /year (FWS)	All Vehicle Crashes	CMV Crashes	Crashes Reduced by FWS				
Monroe_NB	11	33	25	3	17	4	4	21	3	1.00	3
New Buffalo_EB	6	22	17	2	20	2	5	12	1	1.00	1
Grass Lake_EB	7	22	17	2	14	2	4	13	2	0.70	1
Grass Lake_WB	1	4	3	0	2	2	1	3	0	0.70	0
Coldwater_NB	2	12	9	1	6	1	2	8	1	0.20	0
Monroe_SB	7	20	15	2	22	4	6	9	0	0.80	0
New Buffalo_WB	7	28	21	3	8	1	2	19	2	0.40	1
Fowlerville_EB	2	24	18	2	14	5	4	15	2	0.50	1
Fowlerville_WB	4	23	17	2	15	1	4	14	2	0.50	1
Ionia_EB	0	4	3	0	8	2	2	1	0	0.50	0
Ionia_WB	1	7	5	1	7	1	2	4	0	0.50	0
Pontiac_SB	0	22	17	2	15	1	4	13	2	0.20	0

9.8 Appendix 6.1. Sample Computation of Benefit-Cost Ratio (BCR)

PROCEDURE FOR COMPUTING PAVEMENT SAVING (MONROE_NB)

1. Input CADT (7,400) in the simulation spreadsheet.
2. Input queue limit (30 vehicles) and discharge rate (0.7 veh/min).
3. Specify the location WIM overweight percentage (8%).
4. Select and specify truck travel pattern for each hour of the day (24 hrs/day). This is obtained from WIM data analysis.

Hour	Truck Percent
0	2.26%
1	1.96%
2	1.81%
3	2.03%
4	2.43%
5	3.24%
6	3.85%
7	4.81%
8	5.10%
9	5.49%
10	5.83%
11	5.90%
12	5.81%
13	5.68%
14	5.63%
15	5.54%
16	5.33%
17	5.05%
18	4.63%
19	4.30%
20	3.87%
21	3.57%
22	3.11%
23	2.77%
Total	100.00%

5. Input location percentage for Prepass (82% for Monroe) and compute bypass percentage as (1-Prepass-Oeverweight).
6. Obtain number of trucks overweight trucks per day and ultimately in a year by the fixed weigh station location (216,080 trucks).

7. Input the number of overweight trucks weighed per year (216,080 trucks) and CADT (7,400) into the pavement saving spreadsheet. The CADT is used to determine the total number of trucks per year.
8. Set load share accordingly (50/50) and obtain unit cost per ESAL/lane-mile ($0.03/ESAL/lane-mile)).
9. Input trip length (in lane-miles) for the fixed weigh station (292 lane-miles).
10. Distribute the trucks per year based on the region percentages of total trucks by axles for the existing fixed weigh station. Then obtain total truck distribution by axle for the site.

No. Of Axles									
2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
3%	5%	6%	73%	3%	3%	1%	1%	1%	3%

11. Distribute the captured trucks per year based on the region percentages of overweight trucks by axles of the existing fixed weigh station. Then obtain overweight truck distribution by axle.

No. Of Axles									
2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
0%	5%	2%	54%	7%	6%	4%	5%	3%	14%

12. Compute excess load for each axle group as (Overweight ESAL - Normal ESAL).
13. Compute total excess load for each axle group as a result of multiplying the number of overweight trucks distributed by axle by the excess load for each axle group. Then sum excess load to obtain the total (444,610).
14. Compute total pavement saving as total excess load saved (444,610) multiply by ($0.03 /ESAL/lane-mile) and then by multiplying the trip length (292 lane-miles). Total pavement saving ($3,894,784) to use in the life cycle cost analysis.

PROCEDURE FOR COMPUTING TRAVEL TIME SAVING (MONROE_NB)

15. For travel time, input location-specific time spent on bypass lane (0.685 min/truck), mainline (0.4 min/truck) and at the fixed weigh station (4.06 min/truck) in the simulation spreadsheet.
16. Then calculate the added travel time for bypass lane (0.285 min/truck) and fixed weigh station (3.66 min/truck) by subtracting the mainline time spent from each one.
17. Travel time per day can be obtain by multiplying added travel time at the bypass lane (0.285 min/truck) by the number of trucks directed to the bypass lane (740 trucks/day). In similar way, the number of trucks directed to the fixed weigh station scale (592 trucks/day) can be multiply by the added travel time at the fixed weigh station (3.66 min/truck). Total travel time per day is obtain by adding the results of these two operations (2,378 min/day).
18. Input hourly travel time cost of $31.22.
19. To obtain annual cost, convert travel time cost per day in minutes to hours and then multiply by 365 days in a year and the hourly cost of ($31.22).
20. Total travel time saving is ($451,562). This is a disbenefit.

PROCEDURE FOR COMPUTING LIFE CYCLE COST ANALYSIS (MONROE_NB)

21. The first step is to input the project life (30 years). Then, specifying the discount rate (1.9%).
22. In the cost components tabs, input annual labor ($287,789), operating ($47,584) and maintenance ($35,000) costs for the fixed weigh station evaluated.
23. Present value costs result by adding all the costs in a year and then applying the specific discount rate for the year being evaluated.
24. In the benefits tabs, pavement ($3,894,784) and travel time savings (-$451,562) obtained in the previous analyses are input. Note that travel time is a disbenefit, and therefore it is introduced in the benefit side with a minus sign.
25. Determine the present value (PV) for benefits and costs.
26. Determine the Net Present Value (NPV) by subtracting the present value of costs ($8,829,324) from the present value benefits ($78,186,953), giving the NPV of ($69,357,629).
27. The fixed weigh station BCR (8.86) is obtained by dividing the total present value benefits ($78,186,953) by the total present value costs ($8,829,324).

Total NPV	$69,357,629
Present Value Costs	$8,829,324
Present Value Benefits	$78,186,953
BCR	8.86

Note: *These procedures are specifically for Most Advanced fixed weigh stations. In order to compute BCR for Basic, Intermediate and Advanced fixed weigh stations some modifications need to be made to the simulation spreadsheet. Only the changes needed are listed below.*

For Basic and Intermediate:

1. **Step 5**-Assign 100% to the FWS Tab, as all trucks are required to enter the scales. Prepass and bypass tabs would change to zero.
2. **Step 15**- Input the specific travel time spent in the fixed weigh station evaluated and the time spent in the mainline where the station is located.

For Advanced:

1. **Step 5**-Assign the specific WIM overweight percentage to the FWS Tab, as only overweight trucks are required to enter the scales. Input zero for Prepass tab and then the bypass tab would be modified automatically.
2. **Step 15**- Input the specific travel time spent in the fixed weigh station evaluated, the time in its specific bypass lane and the travel time spent in the mainline where the station is located.

For each fixed weight station all the remaining parameters (CADT, WIM overweight percent, scheduled hours, travel time pattern, etc.) are also being modified as each station is different.

9.9 Appendix 6.2. Present Worth of Costs, Benefits and Disbenefits

Individual Fixed Weigh Stations

Weigh Station	Highway	Level	Operating Cost	Labor Cost	Maintenance Cost	Upgrade/Replacement Cost	Pavement Saving	Travel Time	PV COSTS	PV BENEFITS	BCR
New Buffalo_EB	I-94 EB	Most Advanced	$15,726	$287,789	$41,000	$584,352	$1,662,407	($345,790.00)	$8,242,146	$105,214,606	12.77
Monroe_NB	I-75 NB	Most Advanced	$47,584	$287,789	$35,000	$584,352	$865,862	($451,561.55)	$8,829,324	$78,186,953	8.86
New Buffalo_WB	I-94 WB	Advanced	$30,145	$119,912	$41,000	$312,352	$783,814	($321,092.67)	$4,562,446	$46,018,992	10.09
Monroe_SB	I-75 SB	Advanced	$29,876	$215,842	$46,000	$312,352	$747,034	($672,964.47)	$6,848,181	$61,022,179	8.91
Grass Lake_EB	I-94 EB	Advanced	$26,787	$191,859	$33,000	$312,352	$579,259	($310,717.00)	$5,938,256	$23,727,060	4
Grass Lake_WB	I-94 WB	Advanced	$19,439	$191,859	$33,000	$312,352	$579,259	($310,717.00)	$5,771,412	$23,727,060	4.11
Coldwater	I-69 NB	Advanced	$7,006	$57,558	$36,000	$312,352	$195,673	($82,108.00)	$2,507,564	$4,853,159	1.94
Ionia_WB	I-96 WB	Intermediate	$22,635	$143,894	$15,000	$1,170,905	$185,421	($450,027.00)	$5,271,157	($4,402,393)	-0.84
Ionia_EB	I-96 EB	Intermediate	$22,635	$143,894	$15,000	$1,170,905	$185,421	($450,027.00)	$5,271,157	($4,402,393)	-0.84
Fowlerville_EB	I-96 EB	Intermediate	$22,635	$143,894	$15,000	$2,306,905	$158,726	($308,266.00)	$6,515,436	($1,960,906)	-0.3
Fowlerville_WB	I-96 WB	Intermediate	$28,337	$143,894	$15,000	$2,306,905	$158,726	($308,266.00)	$6,515,436	($1,960,906)	-0.3
Powers	US-41 & US-2	Basic	$8,337	$47,965	$6,000	$ -	$359,003	($11,678.00)	$1,414,715	$2,351,656	1.66
Pontiac_SB	I-75 SB	Basic	$9,088	$59,956	$15,000	$ -	$44,407	($128,325.00)	$1,908,424	$1,313,810	0.69
Telegraph	US-24 NB & SB	Basic	$10,615	$11,991	$15,000	$500,489	$22,003	($2,051.00)	$1,345,100	$2,634	0
Cambridge	M-50 & US-12	Basic	$8,337	$47,965	$8,000	$ -	$129,375	($6,464.00)	$1,460,130	$480,014	0.33
OVERALL									**$72,400,883**	**$334,171,527**	**4.62**

Upgrading to Advanced Level

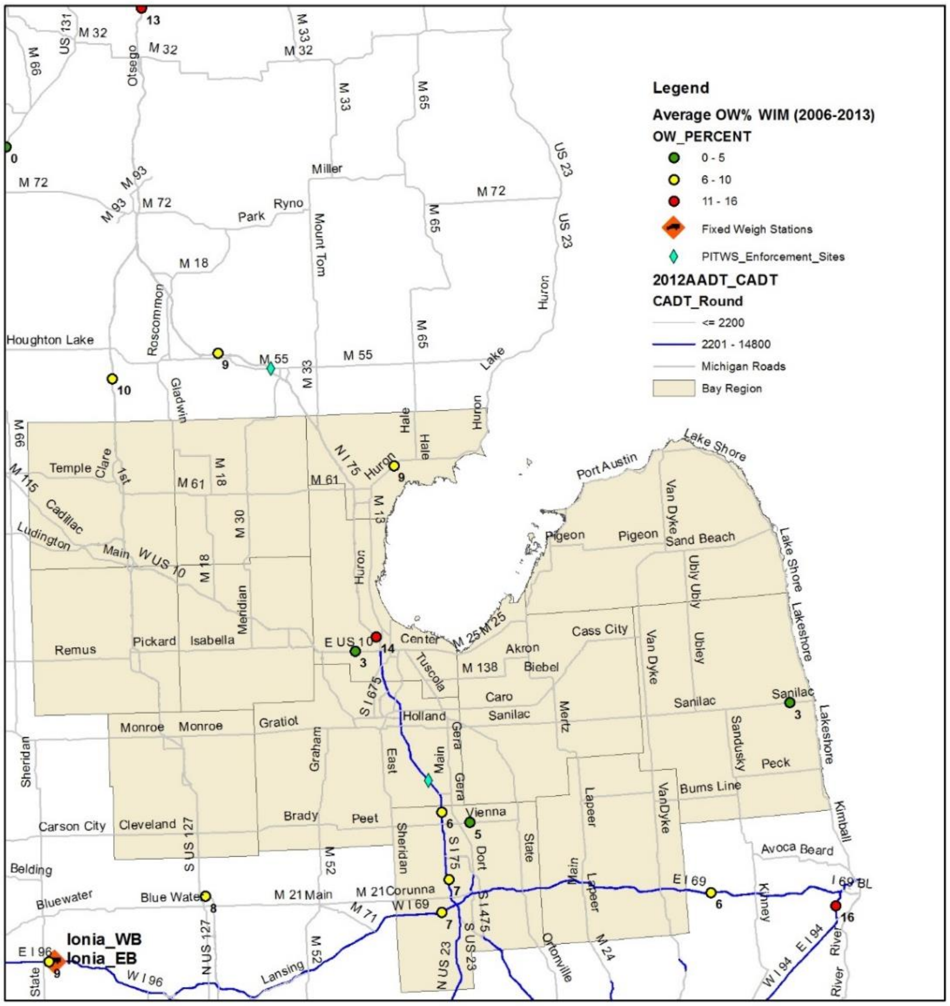
Weigh Station	Highway	Current Level	Operating Cost	Labor Cost	Maintenance Cost	Upgrade/Replacement Cost	Pavement Saving	Travel Time	PV COSTS	PV BENEFITS	BCR
Ionia_EB	I-96 EB	Intermediate	$ 22,651	$ 143,894	$ 37,800	$2,169,933	$751,173	$ (160,811)	$ 6,681,134	$ 13,405,642	2.01
Fowlerville_EB	I-96 EB	Intermediate	$22,651	$ 143,894	$ 37,800	$3,305,933	$621,011	$ (119,437)	$ 7,795,952	$ 11,389,489	1.46
Pontiac_SB	I-75 SB	Basic	$ 22,651	$59,956	$ 37,800	$1,135,028	$240,654	$ (52,358)	$ 3,759,495	$ 4,275,730	1.14
Ionia_WB	I-96 WB	Intermediate	$ 22,651	$ 143,894	$ 37,800	$2,169,933	$751,173	$ (160,811)	$6,681,134	$ 13,405,642	2.01
Fowlerville_WB	I-96 WB	Intermediate	$ 22,651	$ 143,894	$ 37,800	$3,305,933	$621,011	$ (119,437)	$ 7,795,952	$ 11,389,489	1.46
OVERALL									**$ 32,713,666**	**$ 53,865,991**	**1.65**

Upgrading to Most Advanced

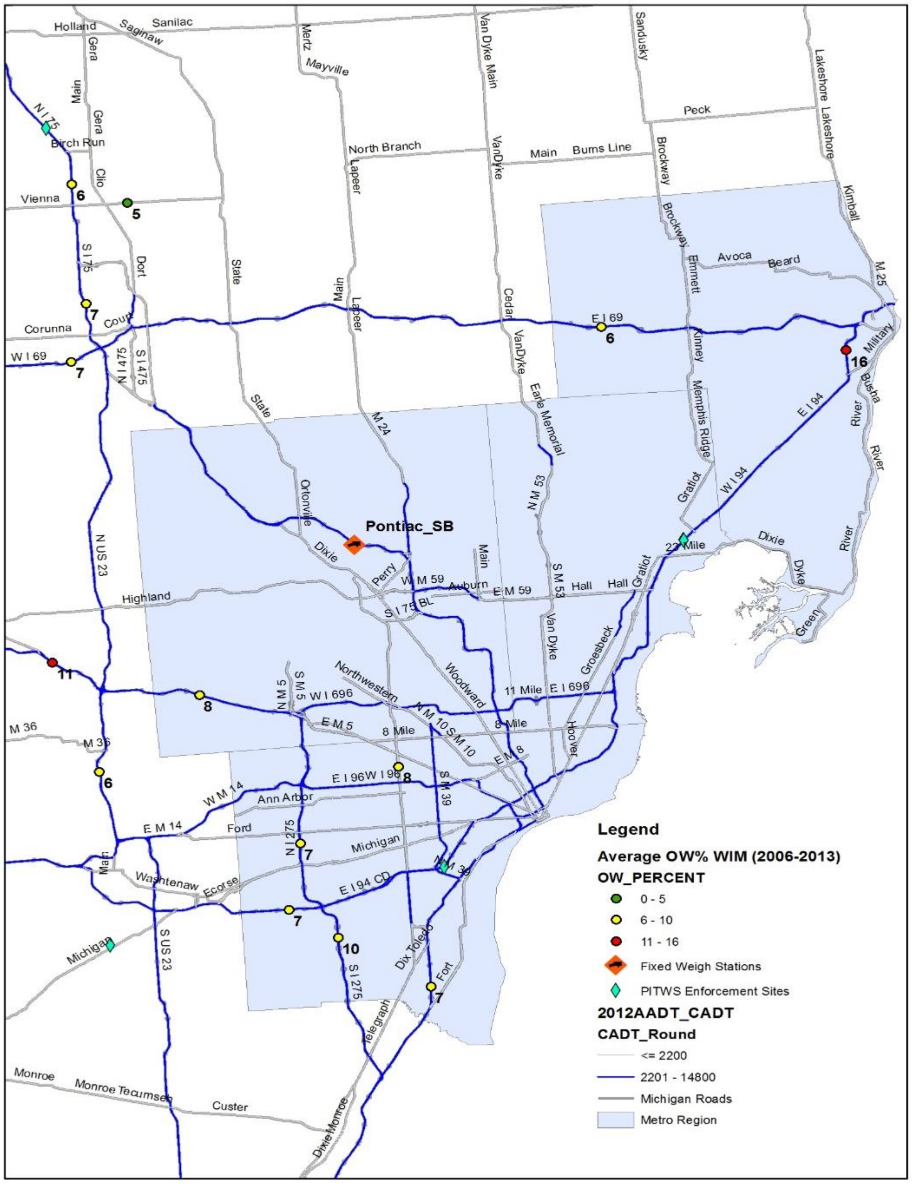
Weigh Station	Highway	Current Level	Operating Cost	Labor Cost	Maintenance Cost	Upgrade/Replacement Cost	Pavement Saving	Travel Time	PV COSTS	PV BENEFITS	BCR
Ionia_EB	I-96 EB	Intermediate	$31,655	$143,894	$38,500	$2,502,280	$751,173	($125,706)	$7,150,561	$14,202,796	1.99
Fowlerville_EB	I-96 EB	Intermediate	$31,655	$143,894	$38,500	$3,638,280	$621,011	($77,783)	$8,265,379	$12,335,357	1.49
Pontiac_SB	I-75 SB	Basic	$31,655	$59,956	$38,500	$1,467,375	$240,654	($29,084)	$4,228,921	$1,714,825	0.41
Ionia_WB	I-96 WB	Intermediate	$31,655	$143,894	$38,500	$2,502,280	$751,173	($125,706)	$7,150,561	$14,202,796	1.99
Fowlerville_WB	I-96 WB	Intermediate	$31,655	$143,894	$38,500	$3,638,280	$621,011	($77,783)	$8,265,379	$12,335,357	1.49
Coldwater	I-69 NB	Advanced	$31,655	$57,558	$38,500	$644,699	$295,833	($38,436)	$3,378,344	$5,844,832	1.73
Grass Lake_EB	I-94 EB	Advanced	$31,655	$191,859	$38,500	$644,699	$1,355,616	($156,593)	$6,427,993	$27,226,819	4.24
Grass Lake_WB	I-94 WB	Advanced	$31,655	$191,859	$38,500	$644,699	$1,355,616	($156,593)	$6,427,993	$27,226,819	4.24
Monroe_SB	I-75 SB	Advanced	$31,655	$215,842	$38,500	$644,699	$3,360,279	($410,326)	$6,972,573	$66,986,039	9.61
New Buffalo_WB	I-94 WB	Advanced	$31,655	$119,912	$38,500	$644,699	$2,347,692	($188,895)	$4,794,253	$49,020,879	10.22
OVERALL									**$63,061,958**	**$231,096,518**	**3.66**

9.10 Appendix 6.3. Overview Maps by MDOT Regions

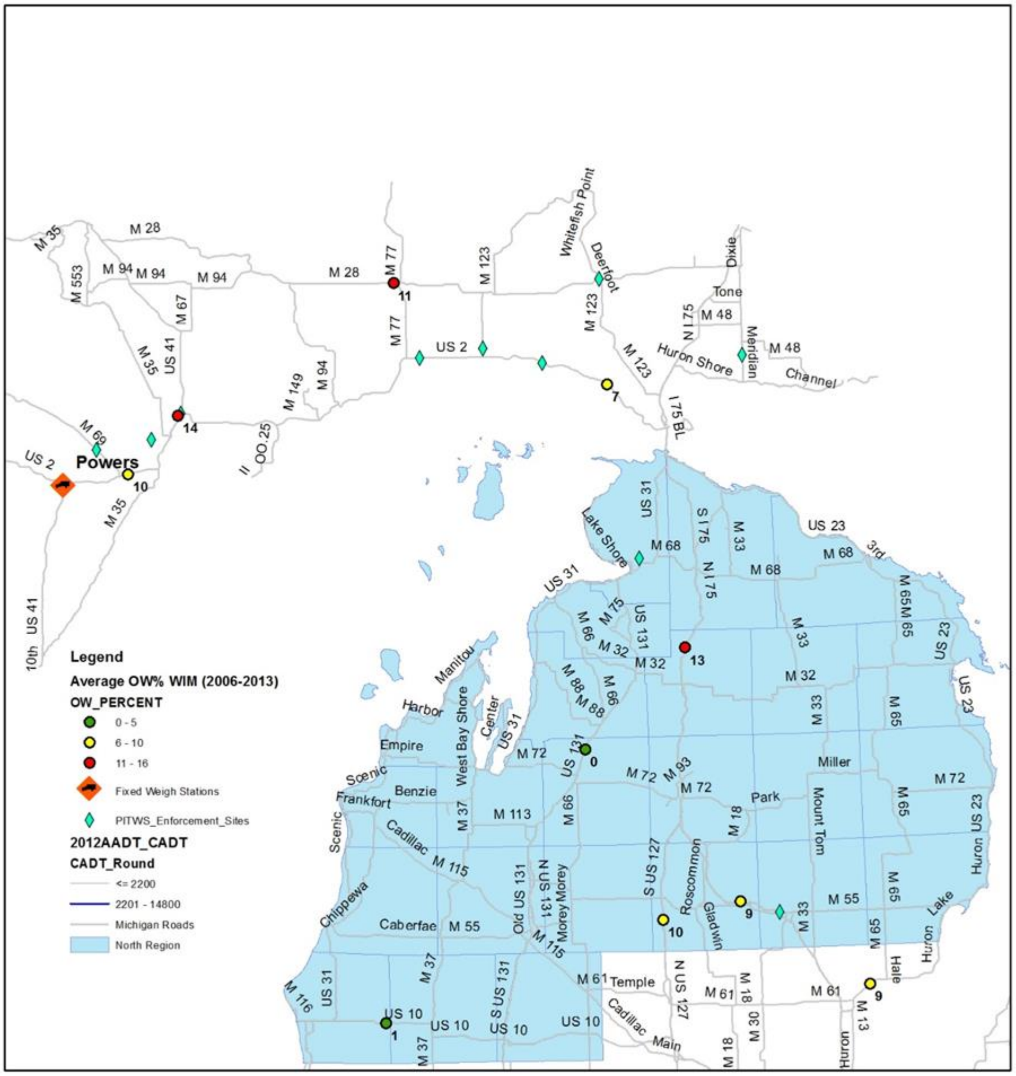
Bay Region



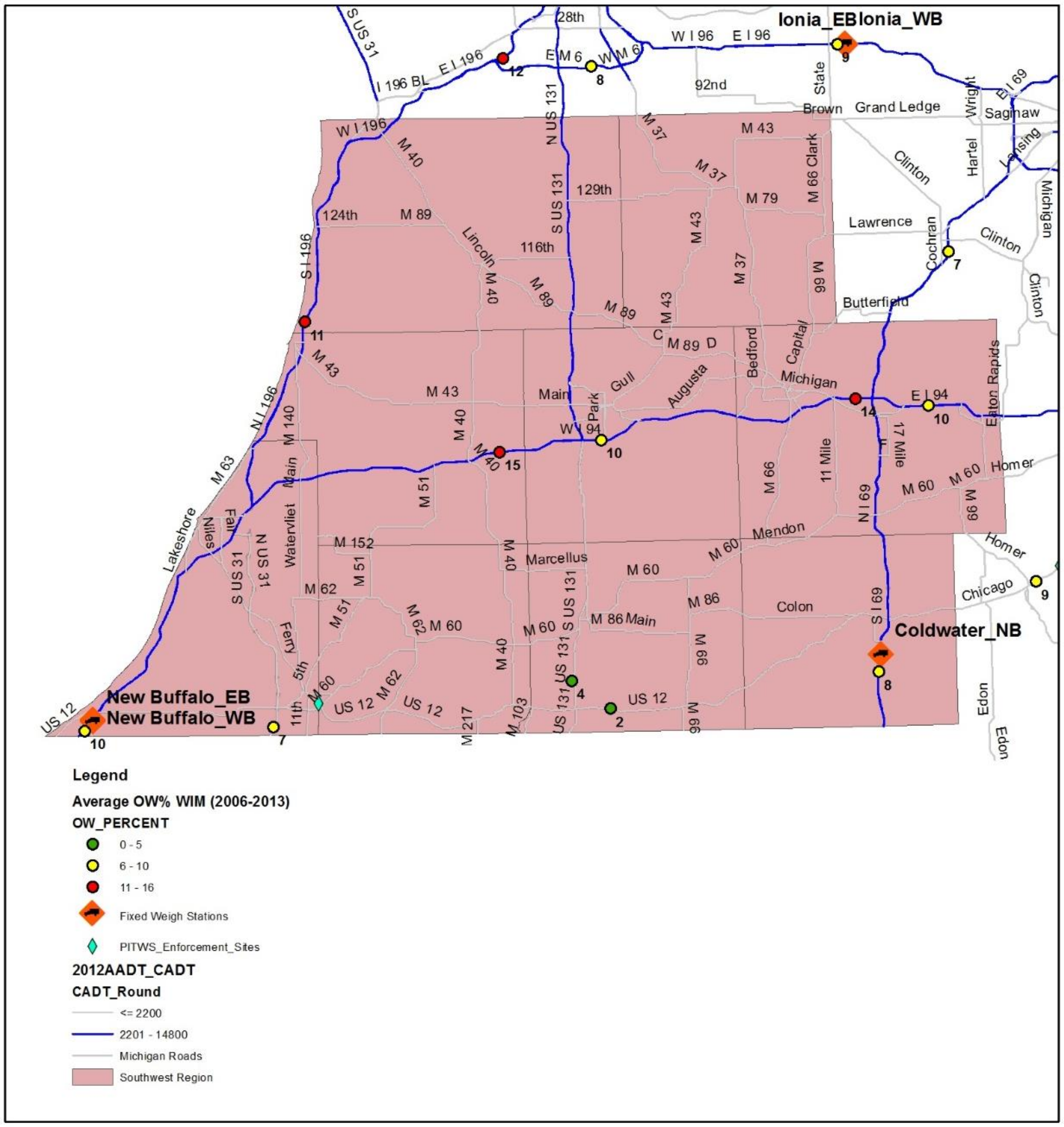
Metro Region



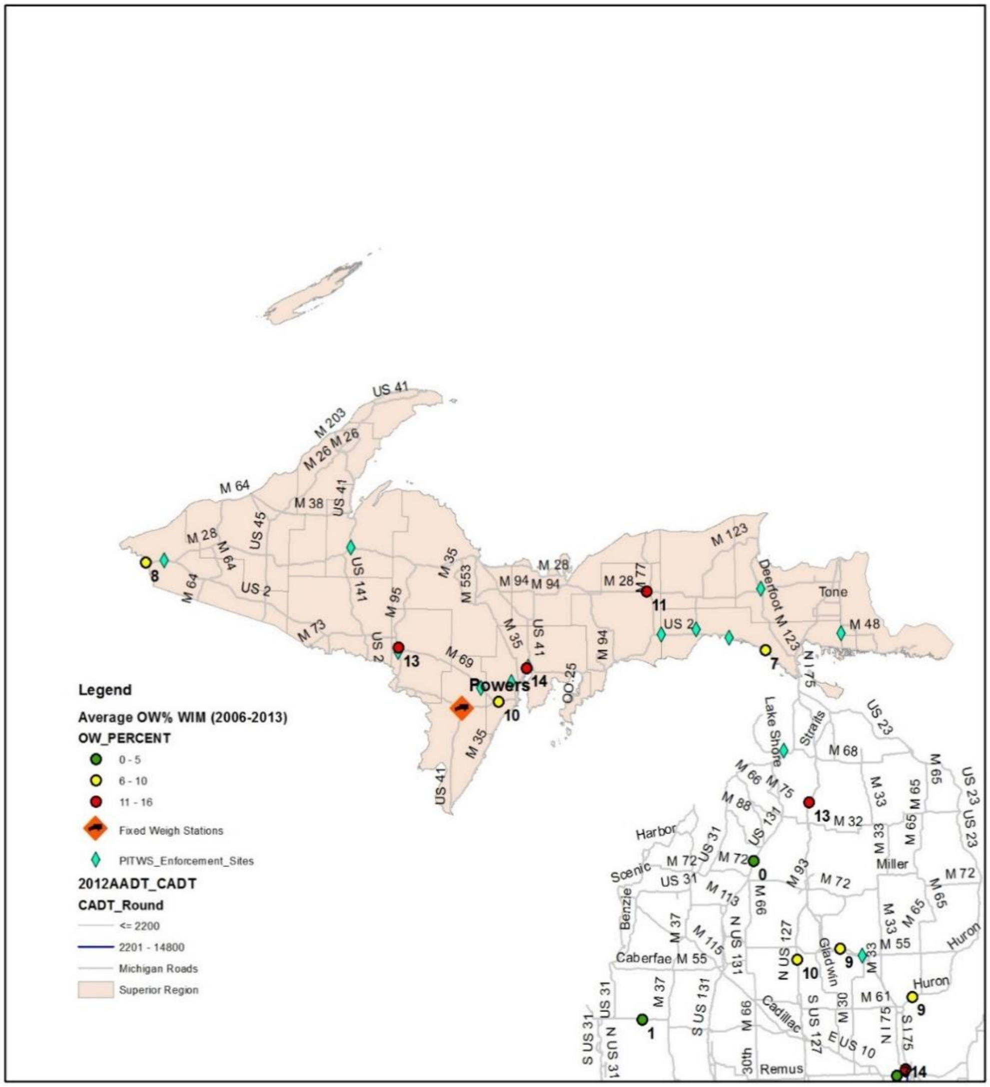
North Region



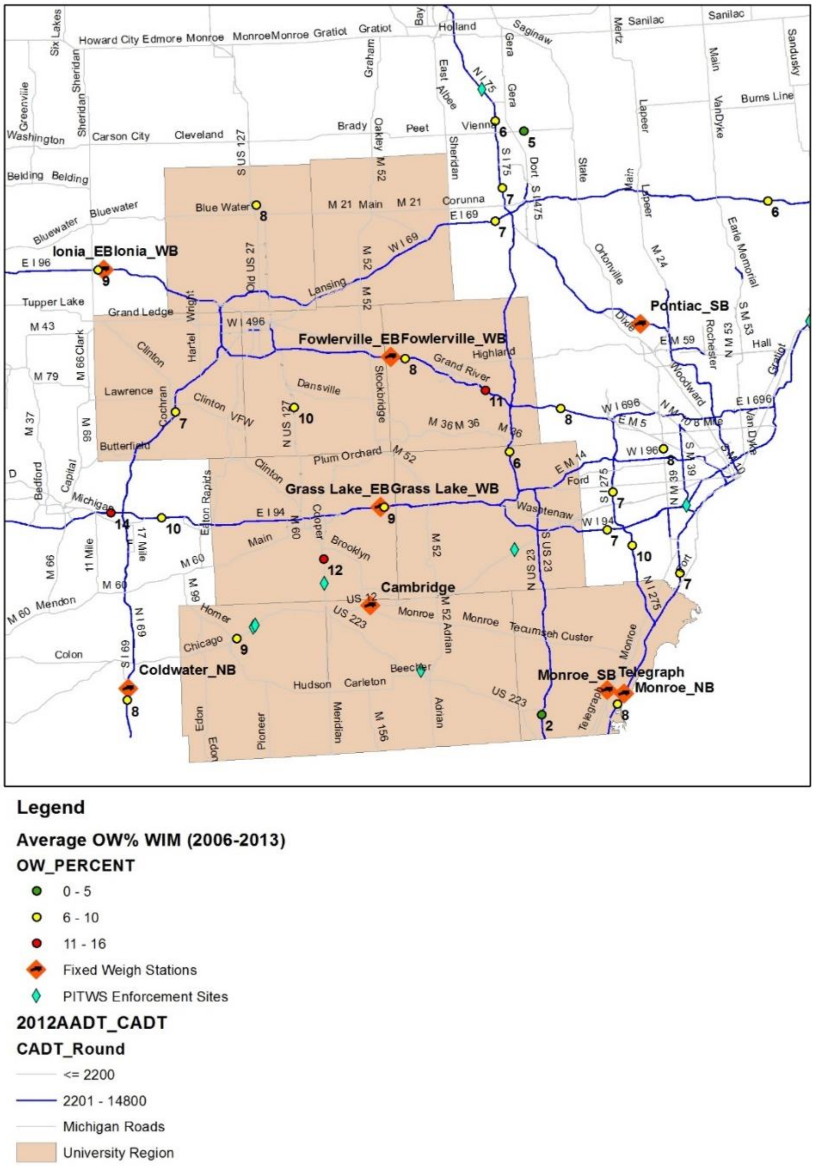
Southwest Region



Superior Region



University Region



9.11 Appendix 7.1. Recommendation for Implementation of Research Findings

Project Title: Evaluating Michigan Commercial Vehicle Enforcement Strategies and Facilities

Project Number: OR13-005

Brief Description of Problem

The growth in truck traffic in Michigan increases the need to improve commercial vehicle enforcement strategies to ensure compliance with the state's weight, size and safety laws. Currently, the Michigan Department of Transportation (MDOT) maintains 15 fixed weigh stations used by the Commercial Vehicle Enforcement Division (CVED) of the Michigan State Police (MSP) as primary locations for enforcing commercial vehicle regulations. The fixed weigh stations are also used for administrative and training purposes. However, when fixed weigh stations are in operation, commercial vehicle operators are quickly aware and may use alternative routes to bypass them. Also, the current layout and technologies available at most fixed weigh stations may not match the truck volumes, hence causing excessive delay to trucks or closing the fixed weigh stations regularly due to queuing problem. With the annual $1 million capital budget for upgrading and maintaining existing enforcement sites and for building new enforcement sites, MDOT and MSP desired to determine the effectiveness of existing fixed weigh stations and the use of alternative technologies and potential enhancements of the fixed weigh stations.

Major Findings

The major research findings include:

- The costs to upgrade and enhance the existing fixed weigh stations with alternative technologies.
- The impact of enforcement on safety, pavement life, and travel time. Ultimately, the Benefit-Cost Ratios (BCR) for alternative enforcement strategies were determined.
- Criteria for fixed weigh stations locations.
- Viable technologies and strategies to enhance and replace existing Michigan enforcement strategies.

How the information will be used by MDOT?

The research findings are expected to be used by MDOT and MSP in decision making of future commercial vehicle enforcement strategies. Specifically, the improvements and enhancements of fixed weigh stations and alternative technologies identified, together with their associated costs, will help MDOT and MSP prioritize infrastructure and technology investments in short term (1-5 years) and long term (6-10 years).

Implementation Action Plan

The implementation action plan consists mainly three components:

2. **Infrastructure improvement:** The research results indicated that a number of existing fixed weigh stations will benefit from upgrades and enhancements. These include Fowlerville (EB and WB), Ionia (EB and WB), and Pontiac (SB). Additionally, the research results indicated that an additional fixed weigh station is most likely needed in Grand region. However, the need to add a new fixed weigh station should be confirmed through further study of truck travel patterns and paths as well as evaluation of potential violation rates. The research findings also suggest that MDOT consider removing Cambridge and Telegraph fixed weigh stations since they are located on low truck volume routes.
3. **Technology integration and data consolidation:** The research revealed that a number of technologies can be installed at fixed locations to allow integration of commercial vehicle data from different sources. The technologies that can be installed include Overview Camera (OVC), License Plate Reader (LPR), and DOT Number Reader (DOTNR). Integration of technologies and consolidation of data will enable electronic identification and verification of safety compliance of commercial vehicles to ensure that officers focus their inspection resources on those vehicles, carriers and drivers most likely to present a significant safety risk. In addition to fixed locations, similar technologies can be installed in mobile trailers to allow officers to patrol and enforce commercial vehicle laws at locations without fixed weigh stations more efficiently. The research analyses indicated

that fixed weigh stations are beneficial on routes where the commercial vehicle average daily traffic (CADT) is more than 2,200, however it is important to have enforcement strategies that can be implemented on routes that experience low commercial vehicle volumes and potentially higher rates of violation. The mobile trailers, coupled with wireless Weigh-In-Motion (WIM) and Permanent Intermittent Truck Weigh Stations (PITWS), have the potential to capture violators on such routes that are not monitored by fixed weigh stations to provide the necessary deterrence.

4. **Further Research:** There are four major areas warranting further research. The first research area will be associated with installation and integration of technologies to consolidate commercial vehicle data from multiple sources. It is imperative that the pilot installation of technologies and data consolidation be coupled with a research study to quantify their effectiveness and inform MDOT and MSP on future implementation. The second research area is on determining whether the proposed new fixed weigh station in Grand region will be redundant. This will require a detailed study of origin-destination patterns of commercial vehicles traveling in the region. The third area is on the possibility of Michigan to develop a statewide preclearance system such as GreenLight (used in Oregon) or Weigh2GoBC (used in British Columbia) or expanding the nationwide systems such as PrePass and DriveWyze. Such systems have the potential to increase the number of precleared commercial vehicles and relieve congestion at fixed enforcement locations. The fourth research area is concerning the location of the sign informing truckers of presence of fixed weigh station one mile ahead. The research findings indicated that the segment of 3000-ft to 5280-ft (1 mile) upstream the fixed weigh stations experience increase in crashes. It is important to conduct further study to evaluate whether locating the sign one mile upstream the fixed weigh station is optimal.

Recommendation for Implementation of Research Findings and Budget Allocation

The recommendations for implementation of research findings presented are based on the current MDOT annual commercial vehicle enforcement budget of $1,000,000. It is recommended that MDOT consider the following improvement and enhancement costs, listed below, when planning the implementation of the research findings. The total budget for all eight components is estimated to be approximately $11,000,000, excluding technology maintenance and any new fixed weigh stations. MDOT may need to increase the current budget by approximately 6 percent (if no new fixed weigh station added) or approximately 40 percent (if a new fixed weigh station is built) in order to implement the proposed improvements and enhancements in ten years.

1. The base cost for reconstructing Fowlerville EB fixed weigh station is $1,857,000 while the cost to upgrade to advanced level (i.e., adding a bypass lane) is an additional $687,000. The total cost to reconstruct and upgrade Fowlerville EB to advanced level is $2,544,000. This investment has the potential to increase the Benefit-Cost Ratio (BCR) substantially from -0.84 to 2.01.
2. The base cost for reconstructing Fowlerville WB fixed weigh station is $1,857,000, while the cost to upgrade to advanced level (i.e., adding a bypass lane) is an additional $687,000. The total cost to reconstruct and upgrade Fowlerville WB to advanced level is $2,544,000. This investment has the potential to increase the Benefit-Cost Ratio (BCR) substantially from -0.84 to 2.01.
3. The base cost for reconstructing Ionia WB fixed weigh station, excluding the ramps, is $1,171,000. The cost to upgrade to advanced level (i.e., adding a bypass lane) is an additional $687,000. The total cost to reconstruct and upgrade Ionia WB to advanced level is $1,858,000. This investment has the potential to increase the Benefit-Cost Ratio (BCR) substantially from -0.30 to 1.46.
4. The base cost for reconstructing Ionia EB fixed weigh station, excluding the ramps, is $1,171,000. The cost to upgrade to advanced level (i.e., adding a bypass lane) is an additional $687,000. The total cost to reconstruct and upgrade Ionia EB to advanced level is $1,858,000. This investment has the potential to increase the Benefit-Cost Ratio (BCR) substantially from -0.30 to 1.46.
5. The total cost to upgrade Pontiac SB fixed weigh station to advanced level (i.e., adding a bypass lane) is $823,000. This investment has the potential to improve the BCR from -0.31 to 1.14.

6. Integrating and consolidating technologies at a typical fixed weigh station costs $250,000 (in-house) to $400,000 (through a vendor). The annual maintenance cost anticipated is approximately $15,500 to $40,000.
7. The cost of a mobile trailer with OVC, LPR and DOTNR is $250,000. The annual maintenance cost is estimated to be $25,000.
8. The cost for installing a wireless WIM with PITWS is approximately $350,000.

Short-Term Plan (Years 1-5)

Assuming the $1,000,000 annual budget (i.e., $5,000,000 in five years), it is recommended that the following improvements/investments be performed during the first five years:

- Reconstruct Ionia EB fixed weigh station and add a bypass lane (i.e., upgrade to advanced level). This is expected to cost $1,858,000 and increase the BCR from -0.30 to 1.46.
- Reconstruct Fowlerville WB fixed weigh station and add a bypass lane (i.e., upgrade to advanced level). This is expected to cost $2,544,000 and increase the BCR from -0.84 to 2.01.
- Implement a pilot of technology and data integration at New Buffalo EB fixed weigh station. It is recommended that a research study be conducted in conjunction with the pilot implementation to quantify the benefits of technology/data integration in order to guide future application. It is anticipated that installation of the technologies (excluding the research component) will cost as low as $250,000 and as high as $400,000.
- In order to improve efficiency of law enforcement officers and increase flexibility in conducting mobile screening, it is recommended that a mobile trailer be acquired and evaluated in conjunction with integration of technologies/data described above. The mobile trailer is expected to improve efficiency by allowing officers to focus on high-risk vehicles, carriers and drivers. It is also expected to increase flexibility by allowing officers to focus on locations with potentially high rate of violation. The mobile trailer is expected to cost $250,000.

Long-Term Plan (Years 6-10)

Assuming the same level of annual budget, it is recommended that the following improvements be considered in a long-term plan:

- Upgrade Pontiac SB fixed weigh station to advanced level (i.e., adding a bypass lane). This is expected to cost approximately $823,000 and potentially improve the BCR from -0.31 to 1.14.
- Reconstructing and upgrading Fowlerville EB fixed weigh station to advanced level (i.e., adding a bypass lane), expected to cost $2,544,000.
- Reconstructing and upgrading Ionia WB fixed weigh station to advanced level (i.e., adding a bypass lane), expected to cost $1,858,000.
- MDOT consider analyzing truck origin-destination (O-D) to determine the paths of individual commercial vehicles. This is necessary to confirm the need to add a fixed weigh station in Grand Region. A new advanced fixed weigh station (i.e., with a bypass lane) can cost approximately $3,300,000. It is also important to quantify the potential redundancy resulting from the locations of Ionia and Fowlerville fixed weigh stations.
- Review potential violation rates recorded by WIM sensors to determine which safe enforcement site locations to maintain. This will also help MDOT determine new locations to add wireless WIM sensors that can be used in conjunction with the mobile trailer. The cost of adding one wireless WIM with PITWS is estimated to be $350,000.

Table A7.1. A Summary of Implementation Plan and Budget Allocation

Short-Term Plan (Year 1-5)	**Estimated Cost***
Reconstruct and upgrade Ionia (EB) fixed weigh station	$ 1,858,000
Pilot technology integration at New Buffalo EB fixed weigh station	$ 400,000
Reconstruct and upgrade Fowlerville WB fixed weigh station	$ 2,544,000
Mobile trailer with OVC, LPR and DOTNR	$ 250,000
Total	**$ 5,052,000**
Long-Term Plan (Year 6-10)	
Upgrade Pontiac SB fixed weigh station	$ 823,000
Reconstruct and upgrade Fowlerville EB fixed weigh station	$ 2,544,000
Reconstruct and upgrade Ionia WB fixed weigh station	$ 1,858,000
**Adding new fixed weigh station in Grand Region	$ 3,300,000
Adding wireless WIM with a PITWS	$ 350,000
Total with new fixed weigh station	**$ 8,875,000**
****Total without new fixed weigh station**	**$ 5,575,000**

**Note: Maintenance costs not included*