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Commercial Vehicle Enforcement Innovation

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April 2015

Research Project
Final Report 2015-17

Technical Report Documentation Page

1. Report No. MN/RC 2015-17	2.	3. Recipients Accession No.
4. Title and Subtitle Commercial Vehicle Enforcement Innovation		5. Report Date April 2015 6.
7. Author(s) Scott Petersen, Erik Minge, Michael Janson, Anton Tillman, Chris Iverson		8. Performing Organization Report No.
9. Performing Organization Name and Address SRF Consulting Group, Inc. One Carlson Parkway North, Suite 150 Minneapolis, MN 55447		10. Project/Task/Work Unit No. 11. Contract (C) or Grant (G) No. (c) 99542
12. Sponsoring Organization Name and Address Minnesota Department of Transportation Research Services & Library 395 John Ireland Boulevard, MS 330 St. Paul, Minnesota 55155-1899		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code
15. Supplementary Notes http://www.lrrb.org/pdf/201517.pdf		

16. Abstract (Limit: 250 words)

Conventional methods for detecting vehicles for permanent travel monitoring stations have relied on detecting physical attributes of vehicles without correlating these with the specific vehicles and/or motor vehicle freight operators. However, by using a license plate reader camera, information can be gathered and cross referenced to other known data related to the specific vehicle assigned to the license plate. This could provide additional tools for enforcing overweight vehicles or targeting enforcement communication with freight carriers that consistently violate weight limits. The analysis conducted during this project compared machine-read license plates to manually collected license plates. The license plates were read as vehicle travelled highway speeds in a generally uncontrolled environment. Analysis is also provided that correlates hours of direct sunlight with accuracy of the automated reader.

A second analysis was conducted as an effort to improve the accuracy of the Minnesota Department of Transportation's weigh-in-motion classification scheme and bring it in line with the Department's classification scheme for automatic traffic recorder stations (sites with axle-based detection that do not collect weight information).

17. Document Analysis/Descriptors Automatic license plate readers, Freight transportation, Identification systems, Weigh in motion, Automatic vehicle classification, Traffic surveillance		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 51	22. Price

Commercial Vehicle Enforcement Innovation

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Executive Summary

The Commercial Vehicle Enforcement Innovation project was initially planned to primarily focus on evaluating automated methods for reading commercial vehicle license plates with an additional minor task of providing recommendations for improving the Minnesota Department of Transportation's weigh-in-motion classification scheme. However, the evaluation showed that the license plate reader technology was not accurate enough in an uncontrolled environment for stakeholders. Thus, additional effort was spent on the weigh-in-motion analysis.

Because these two topics are diverse, a final report was written about each one that exclusively focuses on the respective subject. These two reports are compiled in this document and can be found on the following pages.

License Plate Reader Camera Evaluation

Final Report

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Technical Advisory Panel

The following members comprise the project's Technical Advisory Panel that contributed to the development of the testing process:

- Ben Timerson, MnDOT
- Nelson Cruz, MnDOT
- Alan Rindels, MnDOT
- Gene Hicks, MnDOT
- Mark Novak, MnDOT
- Tom Nelson, MnDOT
- Josh Kuhn, MnDOT
- Susan Anderson, MnDOT
- Greg Wentz, MnDOT
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- Major Matt Sokol, Minnesota State Patrol
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Project Overview

The Minnesota Department of Transportation (MnDOT) installed a license plate reader (LPR) camera system at the weigh-in-motion (WIM) site on Trunk Highway 43 in Winona, Minnesota. The project described in this report involved oversight of the installation and accuracy testing of the LPR system.

LPR technology generally uses digital imaging that is processed by an optical character recognition algorithm that converts images of letters and numbers into a text string. This technology is already used in other scenarios, such as police and Minnesota State Patrol squad cars as well as tolling applications. However, those applications differ from the system evaluated in this project because the environment is generally less controlled with respect to either lighting conditions and there is less time for the camera to read the plate.

The project was initiated to help optimize weight enforcement tactics by identifying vehicles that exceeded the weight limit on the Winona Main Channel Bridge. Traditional methods for overweight vehicle enforcement require a substantial amount of State Patrol personnel hours to stop, weigh, and potentially cite overweight vehicles.

Field evaluations were conducted to cross-check with the LPR recordings and calculate accuracies for various plate types. The system's license plate capturing accuracy was tested three times during the day in order to test the system under different lighting conditions. A full month's worth of data was also compiled to study relationships between system performance and weather conditions.

The system uses a two-step process to read a license plate. First, it captures a high-contrast, high-resolution image of the plate. The system was able to capture this image for 44 to 53 percent of trucks during the testing periods. Second, the system uses imaging algorithms to read the plate. The system was able to successfully read 28 to 36 percent of truck license plates (passing both steps successfully). This capture rate was lower than expected, so analysis shifted to understanding why the capture rate was lower than expected and what conditions led to various accuracy rates.

An analysis comparing read rates to lighting conditions was conducted for the month of October 2013. In October there are about 12 hours between sunrise and sunset. For plates that the system attempts to record, it either records an alphanumeric string or indicates that it could not read the plate (the system only attempts to read plates for which it can capture an image file). Of the plates for which it captures an image file, the system generates an alphanumeric string for about 75 percent of truck records on days with primarily sunny weather and about 55 percent on days that were primarily overcast. The ability of the system to generate the alphanumeric strings varied throughout the day with the best read rates occurring during daylight hours.

Another important factor was the configuration of the character string on the license plate. The LPR camera needed to be adjusted to include character strings common to Minnesota and Wisconsin license plates. The analysis was conducted after this change was made.

Ultimately, it was found that the license plate images would be useful to identify vehicles and present probable cause that the truck was overweight in court. However, the license plate character recognition for the LPR system was too low to use for other efforts such as targeting carriers. Additionally, the State Patrol was concerned with legislation which would prevent or inhibit LPR technology and ultimately decided to not pursue its use.

Chapter 1. System Overview

This section describes the project background that led to the installation of the LPR camera, an overview of the system, a description of the LPR camera installation, and considerations for operation and maintenance of the LPR camera.

1.1 Background

MnDOT deployed the Minnesota TH 43 WIM system to monitor truck traffic on the Main Channel Bridge over the Mississippi River near Winona, Minnesota. This bridge is listed as “fracture critical” and has been regulated to disallow trucks weighing more than 80,000 pounds. The WIM equipment monitors traffic crossing the Mississippi River Bridge that connects Winona and rural Wisconsin.

The following timeline illustrates the need for weight enforcement.

- In the fall of 2009, WIM equipment was installed to monitor truck loads.
- In June 2010, the bridge was posted for only legal loads, no overweight loads. The sign is shown in Figure 1.1.
- In October 2010, a total of 5,086 overweight vehicles crossed the bridge.
- In fall of 2010, an “overview” camera capable of viewing southbound traffic entering from Wisconsin was installed that showed MnDOT and State Patrol images along with vehicle weights.
- In June, 2011 an LPR camera was added to capture license plates of southbound traffic.

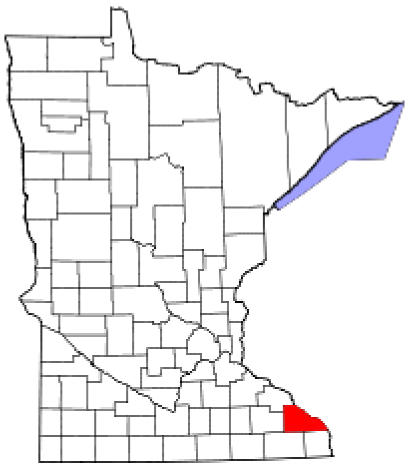
Figure 1.1 Weight Restriction Sign

Traditional methods for overweight vehicle enforcement require State Patrol personnel to mobilize to the WIM site and set up enforcement operations. After setting up, they can typically perform enforcement activities for three to four hours and then mobilize back to their home base. It takes from 45 minutes to one hour to inspect a vehicle, weigh the vehicle, review equipment ratings, review permitted equipment ratings and write tickets. The State Patrol may only be able to ticket three or four vehicles per day, which may not deter overweight vehicle drivers from crossing the bridge.

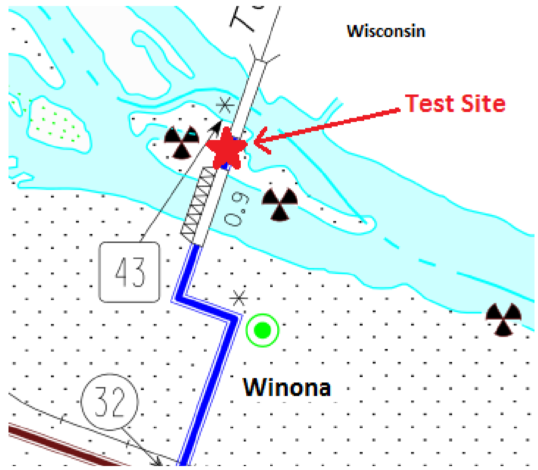
International Road Dynamics (IRD) integrated the LPR system. MnDOT installed the LPR Camera. The company that provided technical support for the camera throughout the project changed among several companies. When the camera was purchased, the vendor was PIPS (part of Federal Signal). PIPS was later sold to 3M. This report refers to the “LPR system vendor” which represents personnel from these companies.

1.2 Test Site Description

The test site is a two-lane highway, with a speed limit of 45 mph and an annual average daily traffic count of around 10,500 as of 2012. MnDOT refers to this site as WIM Site 39. Location maps are shown in Figure 1.2.



Winona County, Minnesota



Test Site

Figure 1.2 Site Location

1.3 License Plate Reader Installation

1.3.1 General Installation and Startup Performance

Although there was an initial delay in procuring the camera mount, the installation process took approximately 2-1/2 hours which included attaching the arm extension, running cables, mounting the LPR camera and terminating cables.

The LPR camera was mounted on a newly installed “non-intrusive detection” tip-down pole. The camera is attached to an extension arm to reduce the incidence angle with traffic thereby improving the optical character recognition (OCR) accuracy. The pole tips away from traffic on TH 43. The pole may be tipped down to facilitate maintenance, avoiding the need for a bucket truck for most maintenance procedures. However, a short ladder is still needed to reach the camera when the pole is tipped down due to the extension as shown in Figure 1.3.

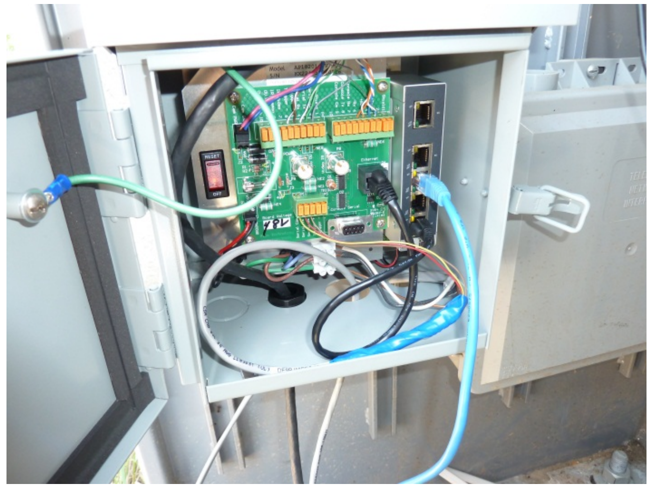
Figure 1.3 Camera Installation

The hinged pole rests on a concrete base as shown in Figure 1.4. In order to tip the pole down, three 1/2-inch bolts must be unscrewed from the base. Two operators are required to lower the pole to the ground. Two conduits run from the pole base to a nearby handhole.

Figure 1.4 Hinged-Pole Base Mechanism

To configure the LPR software and aim the camera in the field, a portable computer with the LPR control software can be connected to the WIM interface box located inside the WIM cabinet. Figure 1.5 shows the LPR camera's interface box located in the lower left corner of the cabinet.

WIM Cabinet



LPR Camera Interface Box

Figure 1.5 WIM Cabinet and LPR Camera Interface Box

1.3.2 LPR Camera Aiming

The LPR camera was aimed at southbound traffic manually by an operator in a bucket truck. The aiming process took approximately 30 minutes. Test photos were taken and the LPR camera view was adjusted until the aiming was correct. The camera aiming process is shown in Figure 1.6.

The camera initially read fewer license plates than expected. The LPR system vendor recommended aiming the camera differently to improve the capture rate.

Figure 1.6 Camera Aiming with Bucket Truck

1.3.3 LPR Algorithm

Upon installation, the LPR camera was able to read many non-commercial Minnesota and Wisconsin license plates but not most commercial vehicle license plates. The OCR algorithm needed to be updated to read a higher percentage of commercial plates. The LPR system vendor asked MnDOT to capture bitmap images for it to use to develop an OCR algorithm for reading Minnesota and Wisconsin commercial vehicle plates. The LPR system vendor refined the algorithm using images; this refines algorithm was used in subsequent testing.

1.3.4 Maintenance Requirements

The LPR camera is generally maintenance-free. The lens is exposed to the elements, but is recessed in the camera housing. The camera is positioned far enough from the traffic lanes to avoid direct salt spray. If the camera lens becomes dirty, it may need to be cleaned. All calibration and maintenance of the camera is done in the factory. All the LPR processing is done within the camera assembly and the license plate text string is sent to the cabinet. The interface box primarily provides power and communications, but does not perform computing tasks.

Chapter 2. Test Methodology

The LPR camera was evaluated in a range of weather and sunlight conditions to determine data collection accuracy and determine license plate discrepancies. The site has no electrical lighting, so the entire site's light originates from ambient light or from an infrared illuminator. This section explains other factors that went into the analysis and how the test was conducted.

2.1 License Plate Factors

License plates have various styles depending on the vehicle type. However, the surface appearance, plate material texture, and range of allowable characters are generally consistent for a given state. Minnesota is transitioning to digitally printed license plates that have black lettering and do not have embossed lettering. The style of license plate used previously had embossed blue lettering. Wisconsin is in the process of completing the transition from plates with red lettering (shown in Figure 2.1) to plates with black lettering. The LPR system vendor said that the red lettering is especially difficult for the LPR camera to read. Various styles of plates are shown in Figure 2.2.

Figure 2.1 Red-Letter Embossed License Plate

Minnesota Non-Commercial Plate

Wisconsin Non-Commercial Plate

Minnesota Truck Plate

Wisconsin Truck Plate

Wisconsin Plate
with Stacked Characters

Wisconsin Trailer Plate
with Stacked Characters

Figure 2.2 Various License Plate Configurations

2.2 Manual License Plate Verification

System-recorded license plates were compared to license plates manually read in the field as vehicles drove by the LPR camera. Manual recording periods were conducted in the morning, afternoon, and evening.

Additionally, records were downloaded from the LPR camera that contained an overview image and the “patch” file image that showed the high contrast, high resolution image of the license plate. The files also included information about vehicle characteristics from the WIM site, but these were generally not considered in the LPR accuracy analysis.

2.3 Month-Long License Plate Read Rates

The analysis shifted to a month long analysis when it was determined that the system only generates OCR text for plates which also have the high-contrast, high-resolution “patch” files. License plates that were not read displayed “NOREAD” (no read) instead of a license plate character string. A longer term data collection period allowed for a greater range of analysis including varying lighting conditions. Data from October 9th was analyzed in more depth as a sample day.

Chapter 3. Evaluation Results

This section presents test results. The first section shows how accurately the LPR system functioned in clear conditions at various times of day. The second section shows data compiled over the course of a month.

3.1 License Plate Recognition at Various Times of Day

There were three separate field test periods to compare manually-read license plates to the LPR system output. Each period lasted for two hours during which truck license plates were recorded. The objective was to test the effect of lighting on the accuracy of the data. The testing periods occurred on:

- September 20th, 8:40 am – 10:40 am (morning period, after sunrise at 6:51 am)
- October 9th, 3:30 pm – 5:30 pm (daytime period, before sunset at 6:35 pm)
- October 9th, 8:30 pm – 9:00 pm (nighttime period, after sunset at 6:35 pm)

For the nighttime test, data collection was halted after 30 minutes due to a lack of trucks and poor visibility. The light shining from oncoming headlights made it impossible to manually discern license plates. The LPR system had similar issues. Back license plates were more readable, but the lack of trucks made this test problematic to run. The testing conditions are shown in Table 3.1.

The LPR system records an image of the front of the vehicle. If it can discern a license plate, it produces a “patch” file which is a high contrast, zoomed-in image of only the license plate. The “patch” files must be successfully captured in order for the system to read the license plate. The frequency of patch files captured is shown in Table 3.2. The percentage of correctly read license plates for non-commercial vehicles was much higher, but was not a part of this evaluation. Those license plate patterns are generally easier to capture because they are usually a fixed configuration with sets of three numbers and three letters.

Table 3.1 Testing Conditions

Date	Time Period	Conditions, Temperature (degrees F)	Vehicles Captured	“Patch” File Recorded (High-Contrast, High-Resolution Image)
September 20, 2013	Morning	Overcast, 59	91	53% of Class 4+
October 9, 2013	Daytime	Clear, 75	72	44% of Class 4+
October 9, 2013	Nighttime	Clear, 59	0*	Not Applicable

Table 3.2 LPR and File Comparison

	Morning Period (9/20/2013)	Afternoon Period (10/9/2013)
Total Trucks	91	72
Patch File Recorded	48 (53%)	32 (44%)
Patch File Not Recorded	43 (48%)	40 (56%)
License Plate Captured Correctly	33/91 (36%)	20/72 (28%)
License Plate Not Captured Correctly	58/91 (64%)	52/72 (72%)

Certain types of truck license plates were more successfully captured than others. Due to the location of the project, the majority of trucks had either Minnesota or Wisconsin-issued license plates. The Minnesota plates were captured in patch files more frequently than Wisconsin plates. The results from two time periods are shown in Table 3.3.

Table 3.3 Percent LPR Capture by State

	Number of Plates (Correctly Read/ Incorrectly Read)	
Attribute	**Morning Period (9/20/2013)**	**Afternoon Period (10/9/2013)**
Minnesota	17/30 (57%)	9/20 (45%)
Wisconsin	12/42 (29%)	5/13 (38%)
Other States	4/4 (100%)	6/7 (86%)
No Plate/Unreadable/Not Read	15	32

Additionally, various license plate letter and number configurations were analyzed. The results of this analysis are shown in Table 3.3. To improve LPR performance, the OCR algorithms could be improved to recognize these prefix patterns more reliably. Additionally, if new license plate configurations are introduced, OCR performance would likely be improved if these patterns were programmed into the system.

Table 3.4 Patch File Capture by Plate Attribute

	Number of Plates (Correctly Read/ Incorrectly Read)	
Attribute	**Morning Period (9/20/2013)**	**Afternoon Period (10/9/2013)**
T prefix, W suffix	5/17 (29%)	1/3 (33%)
TS (Stack)	6/16 (38%)	7/7(100%)
PAK, PAM, PAJ, PAL	17/20 (85%)	8/9 (89%)
Other prefix	7/13 (54%)	5/6 (83%)

3.2 Evaluation of Time of Day versus License Plate Capture Rates

The frequency of LPR license capture was referenced across various scenarios, including weather and differences in sunlight. LPR data for October 2013 was analyzed to determine factors that affect license plate capture rates.

This analysis only covers whether or not the system recorded a license plate (counted as a successful read). This analysis discards data if the system did not capture a patch file. If the LPR was unable to generate an alphanumeric string, it recorded "NOREAD" (no read) for the vehicle. NOREAD values are considered unsuccessful in this analysis. Note that even if the system reads the plate, it may not be correct. None of the data presented in this analysis was manually verified by comparing the data to the license plates.

The number of license plates captured using the LPR system was determined on a per hour basis. A one-day example with corresponding trucks per hour is shown below. The weather was partly cloudy and ranged from 39 to 68 degrees Fahrenheit. Figure 3.1 shows both the read rates and truck volumes. By around 6 am, trucks begin to operate in measurable quantities and the read rate approaches 30 percent. By about 9 am, the read rate increases to about 80 percent and stays in that range until the evening when truck volumes decrease and read rates become more sporadic. By about 7 pm, there are few trucks operating and the read rate is inconsistent. There were almost no trucks operating in the overnight hours.

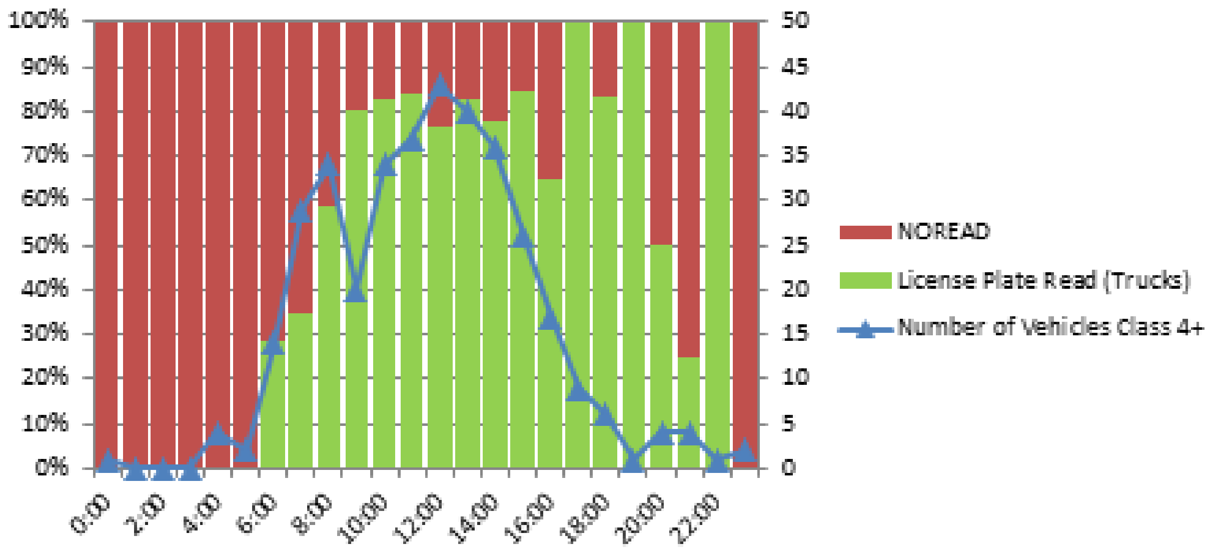


Figure 3.1 Sample Hourly LPR System Performance (October 7th, 2013)

By extending the time of day analysis to the entire month of October 2013, the trend becomes more consistent. The LPR read rates for hours with significant truck volumes are shown in Figure 3.2. The time of day was significant in determining the frequency of LPR license capture. The system captured license plates more reliably during the daylight than the dawn/dusk or nighttime hours.

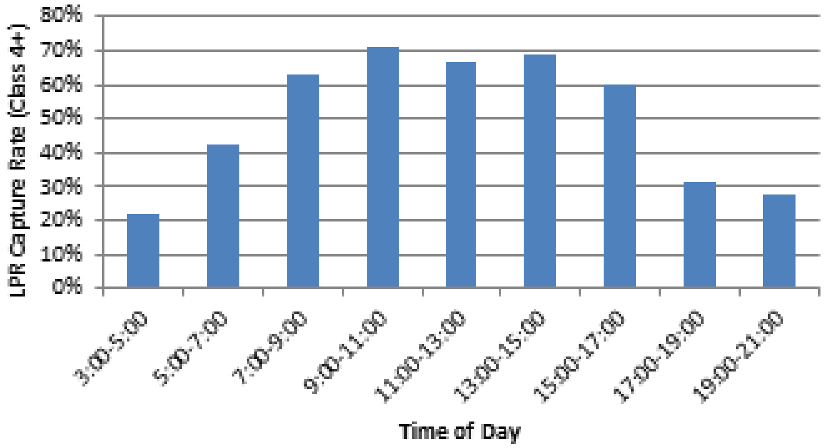


Figure 3.2 LPR Capture Rate, October 2013

Additionally, environmental conditions affect LPR capture performance. In the month of October 2013, the LPR system recorded license plates more frequently during clear days than during overcast conditions or precipitation. A scatter plot showing the accuracy of license plate capture versus hours of sunlight is shown in Figure 3.3. In the graph, each data point represents one day. The weather for each day was considered and the number of hours of sunlight that was not occluded by clouds was estimated. For example, for days that were overcast for the entire day, the estimated hours of direct sunlight is zero.

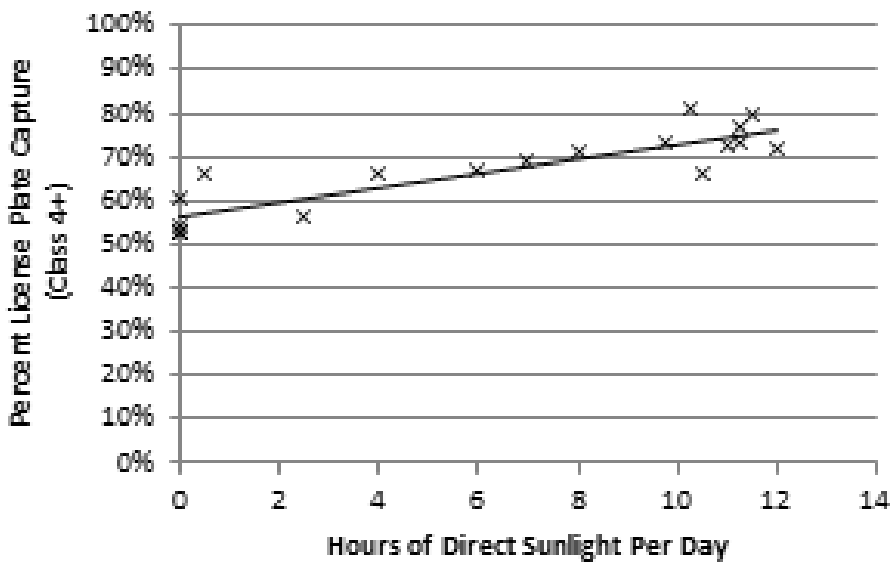


Figure 3.3 Comparison of Hours of Non-Occluded Sunlight versus LPR Capture Rates (October 2013)

3.3 Summary and Additional Considerations

The LPR camera performance is directly related to its ability to record a high-contrast image of the license plate. The following factors were found to be important.

Lighting Conditions. The LPR camera had better license plate capture rates during sunny periods. The system had poor performance at night. The lack of ambient lighting allows light from headlights to wash out all other light and makes it difficult to record a clear image of the license plate. However, there are few trucks operating at night so this may be a less important consideration. However, during the fall and winter, the sun sets before many trucks generally stop operating for the day.

License Plate Condition. The system appears to have performed better when reading relatively clean and/or new license plates. Of the license plates for which the system generated a patch file, but were not correctly read, the system sometimes missed part of the license plate and cut off characters. The system does not read license plates with red characters, such as the Wisconsin plates that are now discontinued.

License Plate Character Patterns. Many truck license plates have prefixed or suffixed characters that follow different patterns than non-commercial plates. They sometimes have stacked characters which are more difficult for the system to read unless the system is adequately configured to recognize those patterns. Stray marks on license plates also contributed to the system not reading the plate properly.

System Analyzed Wrong Image. The system sometimes processed a character string that was not the license plate including USDOT numbers and other characters on the sides of vehicles in the opposing lane. Another failure type included mistakenly capturing northbound vehicles passing slower moving vehicles in the other lane.

Chapter 4. State Patrol Coordination

One of the impetuses of this evaluation was to understand the accuracy of the system so that the Minnesota State Patrol could understand the data quality with respect to their enforcement operations. If the system was accurate enough, automated methods could have been set up for automatically summarizing truck data by carrier. These summaries could be used to target enforcement times and communicate with trucking carriers as a preemptive effort to encourage weight compliance.

However, the Minnesota State Patrol indicated that the primary use of the system would be to have a record of the image of the license plate (whether it was read or not) that could be referenced to give probable cause that the vehicle was over the weight limit. The State Patrol would not use character recognition data from the system and thus the efforts to integrate and summarize data were cancelled.

Additionally, in 2013 and 2014, there were several proposed bills that would limit the use of automated LPR data. Although these bills have been thus far unsuccessful ("Automated License Plate Readers," 2015), there is a general attitude that LPR technologies for this enforcement use case do not provide enough utility compared to their costs.

Chapter 5. Conclusion

Although the character recognition system was found to not meet the needs of the Minnesota State Patrol, this project produced some findings that may help with future deployments of similar technologies. The system would still be useful to provide a reference that the overweight vehicle was in fact the one that was stopped for potential citation. Primarily, the lighting conditions were found to be critical to obtaining good license plate read rates. Most truck traffic travels during daytime hours, but particularly in the fall and winter, some of those hours occur when it is dark. Permanent lighting at the site would allow the system to produce a better image of the license plates.

LPR and overview camera systems can be installed with infrared illuminators. Typical illuminators provide enough light to view the vehicles, but not with the resolution and clarity of the images the system produces in daylight conditions.

High speed license plate recognition is a difficult task. Future implementations of this technology should consider methods to control the lighting and the license plates specific to the local jurisdiction. This may require significant additional effort and expense beyond the base cost of the LPR camera and mounting hardware.

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National Conference of State Legislatures. (2015, March 3) "Automated License Plate Readers" Retrieved from http://www.ncsl.org/research/telecommunications-and-information-technology/2014-state-legislation-related-to-automated-license-plate-recognition-information.aspx

Weigh-in-Motion
Classification Scheme Analysis

Final Report

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Project Overview

Traffic data collection with weigh-in-motion (WIM) technology is an important part of the Minnesota Department of Transportation's (MnDOT) travel monitoring program. This method provides two primary benefits over other more predominant types of traffic detection. First, the system is able to provide vehicle weights that can be analyzed to understand vehicle loads. Second, this method provides axle weight data along with axle spacings that can be used to give better classifications. One of the primary uses for this information is for pavement design. Knowledge about vehicle loading can help pavement engineers design the roads for the expected traffic. Other data collection methods do not produce equivalent single axle loads (ESALs).

However, the classification scheme, the algorithm that is used to classify vehicles, must be carefully constructed to be able to classify as well as possible. The classification scheme needs to cover the range of vehicles that traverse the sites and needs to be accurate. In many cases, the classification is clear cut. In others cases similar axle spacings and weights may be produced by vehicles with different classifications. The classification baseline reference is generally provided by a manual check against a classification scheme provided by MnDOT that is based on standard criteria from the Federal Highway Administration (FHWA). MnDOT has installed "overview" cameras at several WIM sites that allow an operator to manually compare vehicles against the system-generated classification.

MnDOT currently uses a WIM classification scheme for weigh-in-motion that was developed internally. This algorithm provides correct classification for most vehicle classes, but can falter with edge cases. MnDOT has extensive experience with its automatic traffic recorder stations and has refined this scheme over many years. The Automatic Traffic Recorder (ATR) scheme only uses axle spacings to classify vehicles.

This project aimed to converge the WIM classification scheme and ATR schemes. The ATR scheme is "tried and true" and reflects vehicles that travel in Minnesota. It was desired to not adjust the ATR scheme significantly. Thus, only some minor modifications were made to the ATR scheme to make it compatible with the WIM classification scheme. Then, the weights were added to the ATR scheme to produce the WIM scheme. Because the ATR scheme is less restrictive than the WIM scheme, the WIM scheme has additional classifications for vehicles with the same axle spacing.

Additionally, MnDOT identified classification issues that it had noted with regular use of the WIM system, such as pickup trucks with light trailers being classified as multi-unit trucks. This project considered these issues when possible when developing the revised classification table.

The product of this research is a hybrid scheme that unifies ATR and WIM schemes that is provided as an appendix to the document. This revised scheme may improve WIM classification over the currently used scheme although this was not directly tested. Additionally, the revised scheme is unified with the ATR scheme such that future edits to the WIM scheme and ATR scheme can be made universally so that both schemes benefit from the modification.

Chapter 1. Introduction

This report documents proposed revisions to MnDOT's weigh-in-motion (WIM) classification scheme as well as minor modifications to MnDOT's automatic traffic recorder (ATR) classification scheme. WIM systems promise improved vehicle classification over axle-only classification methods by incorporating weight information to classify vehicles.

The WIM scheme that MnDOT currently uses is referred to as MINN6. This scheme generally accurately classifies large vehicles such as semi-trailer trucks, but sometimes misclassifies smaller single-unit trucks because of the large variation of weights of these vehicles.

Initially, the MINN6 scheme's error was noted by viewing records with the iAnalyze software. This observation helped target common classification errors.

It was assumed that minivans and SUVs may be classified as either class 2 or class 3. These vehicles have variable wheelbases because some are mounted on truck chassis.

The following misclassifications were commonly observed with the MINN6 scheme:

- Class 1 motorcycle classified as class 2
- Class 2 passenger cars classified as class 3 or class 5
- Class 2 SUV and minivans classified as class 5
- Class 2 passenger car with trailer classified as class 8
- Class 3 pickup trucks classified as class 2 or class 5
- Class 5 truck classified as class 3

During the period with heavy motorcycle traffic, many records were analyzed to determine how accurately the MINN6 scheme classifies motorcycles. Many motorcycles were misclassified as passenger cars.

This report describes steps that may improve the WIM classification scheme for MnDOT's use. The recommended WIM classification scheme is included in Section 4 of this report and it unifies the ATR and WIM schemes.

Chapter 2. Methodology

This section describes the tools and analysis methods that were used to process the data and determine the class bins.

2.1 Data Set

MnDOT installed "overview" cameras that record an image of each vehicle that passes the WIM site. A sample image is shown in Figure 2.1.

Figure 2.1. Sample Overview Camera Image

The cameras are typically configured to only record classes 4+ (generally trucks), but MnDOT modified the system to record all vehicles for a select periods. Due to bandwidth constraints, the majority of the data analyzed was for classes 4+, although an effort was made to also record classes 1-3 (generally passenger vehicles) for a limited amount of time.

The data for this analysis came primarily from two of MnDOT's WIM sites. These sites were selected because they had recently been calibrated.

- WIM 26 on I-35 in Owatonna (All data from June 2014, about 690,000 records)
- WIM 39 on TH 43 in Winona (Various data throughout 2013, used to develop scheme)

Data and images from additional overview cameras in the following locations were also considered (a few days for each site from summer 2014, used to confirm findings at alternate sites):

- WIM 33 on US 212 in Olivia
- WIM 36 on MN 36 in Lake Elmo
- WIM 37 on I-94 in Otsego
- WIM 38 on I-535 in Duluth
- WIM 42 on US 61 in Cottage Grove

2.2 Software Analysis Tools

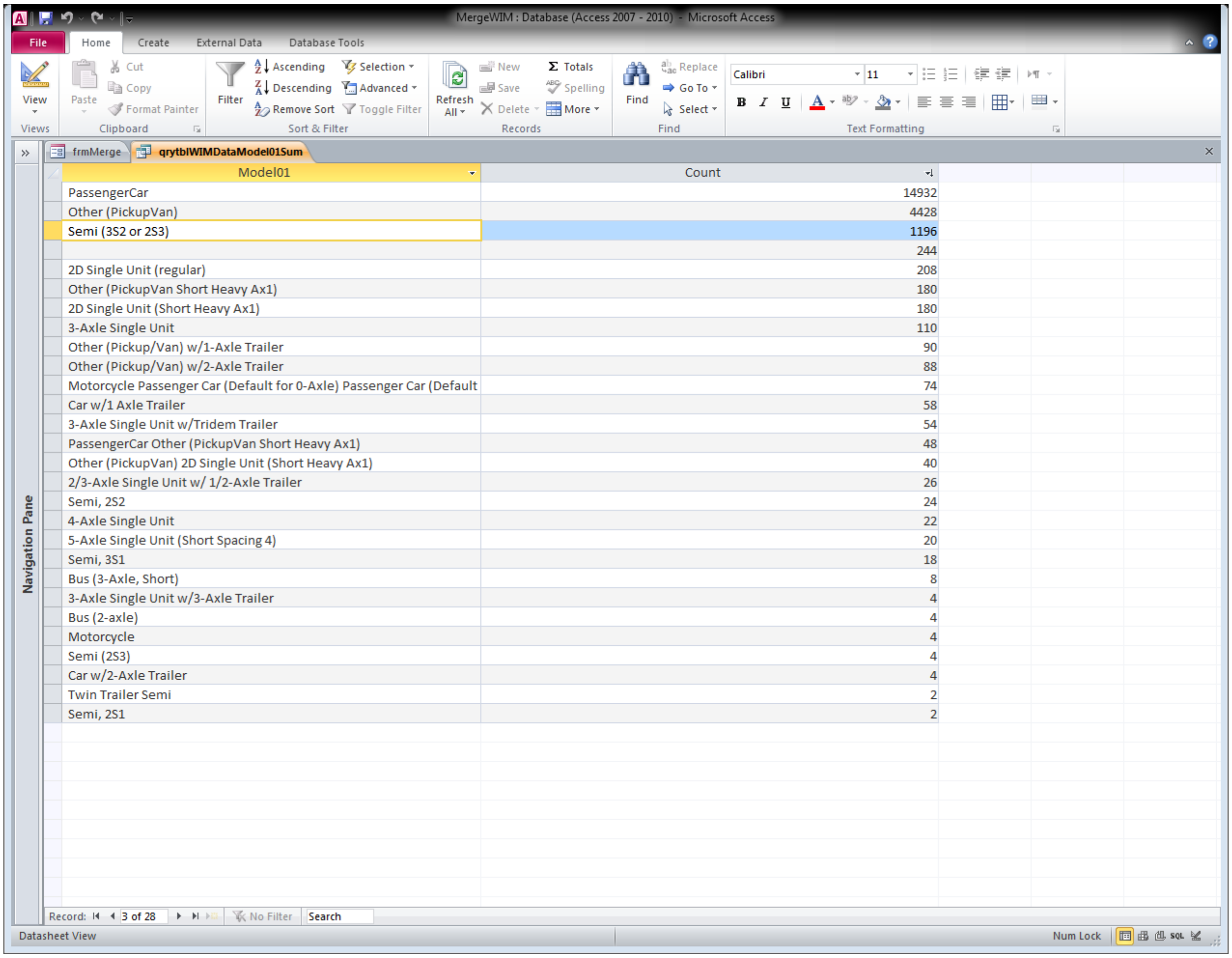
IRD, the WIM system vendor of the sites, analyzed offers software called iAnalyze. This software was used to match images with vehicle records and gain insight into possible WIM classification refinements. The iAnalyze software displays information including the weight of each axle, axle spacing, the class (determined by the MINN6 scheme) and an image of the vehicle if it was available. A sample record is shown in Figure 2.2.

Figure 2.2. Sample iAnalyze Record

Additionally, a Microsoft Access analysis tool was created to perform the classification analysis. This tool allowed the development of new classification schemes and provided the capability to reclassify thousands of records and track changes as they were made to the classification scheme.

Once a dataset had been reclassified, the number of vehicles that were in each class could be viewed. This function showed when a vehicle was classified into multiple classes or left a gap between classes. Unlike an ATR scheme, a refined WIM scheme must inherently have overlap between classes because there are multiple criteria to match.

A summary of one scheme is shown in Figure 2.3. Lines with multiple classifications mean that the vehicle was in two overlapping classes. The line with no records means that the classification scheme could not apply a class to these vehicles. Multiple schemes were developed and assessed with the data set to derive an optimal scheme. This next section discusses this process in detail.



Model01	Count
PassengerCar	14932
Other (PickupVan)	4428
Semi (3S2 or 2S3)	1196
	244
2D Single Unit (regular)	208
Other (PickupVan Short Heavy Ax1)	180
2D Single Unit (Short Heavy Ax1)	180
3-Axle Single Unit	110
Other (Pickup/Van) w/1-Axle Trailer	90
Other (Pickup/Van) w/2-Axle Trailer	88
Motorcycle Passenger Car (Default for 0-Axle) Passenger Car (Default	74
Car w/1 Axle Trailer	58
3-Axle Single Unit w/Tridem Trailer	54
PassengerCar Other (PickupVan Short Heavy Ax1)	48
Other (PickupVan) 2D Single Unit (Short Heavy Ax1)	40
2/3-Axle Single Unit w/ 1/2-Axle Trailer	26
Semi, 2S2	24
4-Axle Single Unit	22
5-Axle Single Unit (Short Spacing 4)	20
Semi, 3S1	18
Bus (3-Axle, Short)	8
3-Axle Single Unit w/3-Axle Trailer	4
Bus (2-axle)	4
Motorcycle	4
Semi (2S3)	4
Car w/2-Axle Trailer	4
Twin Trailer Semi	2
Semi, 2S1	2

Figure 2.3. Microsoft Access Tool Output

2.3 Methodology

2.3.1 Comparison of ATR and WIM Classification Schemes

The MINN6 scheme was first compared to MnDOT's ATR vehicle classification scheme. The ATR scheme has been vetted over many years and produces generally acceptable results based exclusively on axle spacings.

One substantial difference between the two schemes is axle spacing overlap. The ATR scheme has no overlap because axle spacing is the only information the scheme has for differentiating vehicles. However, the MINN6 scheme has overlapping axle spacing between similar classes because it also relies upon axle weights and gross vehicle weights to differentiate classes.

To give a brief overview of the types of differences between these schemes, the two-axle schemes are shown in Table 2.1.

Table 2.1. Sample Two-Axle Classification Schemes

WIM Scheme						ATR Scheme	
Class	**Spacing 1**	**Axle Weight 1**	**Axle Weight 2**	**GVW**		**Class**	**Spacing 1**
1	0.0-4.9	0-2	0-3	0-6		1	1.0-5.9
2	5.0-9.8	0-4	0-5	0-9		2	6.0-10.0
3	5.0-13.8	0-5	0-7	0-7		3	10.1-13.6
4	6.9-24.0	3-20	0-40	0-60		4	13.7-24.0
5	24.0-41.5	3-20	0-40	0-60		5	24.0-40.0

A problem with the MINN6 scheme is that sometimes both spacing and weights overlap. This means that a given vehicle can be simultaneously classified as two different classes. The classification that is selected usually depended on the order in which classification tree is set up within the classifier. For a scheme that uses axle spacings only, the overlap should be eliminated in order to have an unambiguous classification scheme that assigns each vehicle to only one class bin.

An initial analysis of the original classification schemes found that despite the fact that the MINN6 scheme has the additional weight information over the ATR scheme; the ATR classifications are still reasonably accurate. This was determined by comparing both WIM and ATR classifications to manual visual classification of the vehicles. It was observed that the WIM scheme relies on axle weights which can be less accurate than axle spacings. Axle spacing measurements are consistently accurate to one percent

A guiding principle for the analysis was that the ATR and WIM schemes should be brought in line with each other to yield data that is more comparable. This would also ease future modifications to the scheme. To facilitate this, a "Revised WIM" scheme was developed that has axle spacing groups based on those of the ATR scheme. The WIM scheme also improves upon the ATR scheme with the addition of vehicle weights in many cases. In cases where multiple bins fit a single classification, the bins are broken up into "A" and "B" bins. The Revised WIM scheme is presented in Appendix A.

2.3.2 Classification Scheme Resources

The primary resource used to develop the revised WIM classification scheme is MnDOT's ATR scheme. A secondary reference that was used is the Long Term Pavement Performance (LTPP) program's WIM classification scheme. This program is administered by FHWA, who has devoted significant resources and state stakeholder input to develop the classification scheme on a nationwide scale. Thus, the classification scheme has proven successful to detect a variety of vehicle types. In general, the ATR scheme provided the general rule for the axle spacing criteria and the LTPP scheme provided weight ranges. These guidelines were built upon to tailor the classification scheme to match MnDOT's suggestions for research topics.

2.3.3 Access Tool Analysis

As the revised WIM scheme was developed, test records were run through the revised scheme with the Access tool. The revised scheme classifies approximately 98% of vehicles in the

June 2014 Site 26 data set (about 690,000 records). The misclassified vehicles include heavy class 10s that are above the upper weight bound, class 7 trucks with trailers, and vehicles classified as both class 3 pickups and class 5 trucks. These are common vehicles that were not classifiable or fell into an error range. This is a relatively low percentage and if these vehicles should be classified, it may be reasonable to select a default class based on the number of axles.

Chapter 3. Analysis

3.1 Analysis Topics

MnDOT suggested many classification issues to investigate through this project with the goal that a revised classification scheme would address these issues. Table 3.1 summarizes the classification topics that were examined and the resolution and limitations for each topic.

Table 3.2. Analysis Topics

Topic	Resolution	Limitation
Class 3 pickups with long wheel bases are classified as Class 5 (Single unit, six tire truck)	Refine wheelbase range and weight of Class 3 and Class 5 to sort these vehicles better	A significant number of six-tire pickup trucks have a wheelbase length that overlaps with extended cab 4-tire pickup trucks.
Differentiate Class 8 and Class 9 trucks from single unit trucks pulling a light trailer.	Require the last axle spacing for Class 8 and Class 9 vehicles to be at least 3.9 feet.	About 10 percent of vehicles pulling a light trailer have a last axle spacing greater than 3.9 feet. These may be classified as multi-unit trucks.
Analyze tandem/tridem axles. Classifications should have a minimum axle spacing that corresponds with typical vehicle weights.	Implement minimum axle spacing per class.	Vehicles detected with erroneous axle spacing may not be classified.
Classifications should have a minimum gross vehicle weight that corresponds with the typical range of vehicle weights.	Implement minimum gross vehicle weight per class.	Vehicles detected with erroneous weight spacing may not be classified.
Pairs of Class 2 and Class 3 vehicles that are closely spaced can be combined and classified as a Class 8.	This phenomenon was uncommon in the analyzed data. The front axle must be greater than 5 kips and the loop must not drop the detection for the vehicle to meet this criteria.	None.
Determine the effect of two motorcycles riding side by side.	Only one set of motorcycles riding side by side were found in the provided images. This occurrence is shown in Figure 3.2 and was recorded as an error vehicle and a Class 3 with a tailgating warning.	None.
Determine what vehicles are being classified as Class 14.	These vehicles were most commonly trucks hauling trailers with short last axle spacing, such as a Class 9 with a rear tandem axle or a Class 6 with a pup trailer (shown in Figure 3.1) or misdetections due to the vehicle travelling outside the traffic lane. Further analysis of this topic is presented in Section 3.2.	None.

Topic	Resolution	Limitation
Determine what vehicles are being classified as Class 15 and suggest modifications to classify these vehicles.	Vehicles classified as Class 15 with the MINN6 classification scheme are predominantly vehicles with zero GVW and appear to be misdetections that are invalid.	None.
Determine how to classify vehicles with eight or more axles and what percentage of the total traffic volume these are.	December 2011 data was checked and zero 8+ axle vehicles were recorded. There were 75 7-axle vehicles (61 were classified as Class 10 and 14 were classified at Class 14)	None.
Provide an analysis comparing Equivalent Single Axle Load (ESAL) to vehicle class.	ESAL calculation is most accurately done on a per vehicle basis. The traditionally used metrics of axle spacing and axle weights provide accurate classification without ESAL data.	None.

Figure 3.4. Class 6 Truck Hauling a Pup Trailer

Figure 3.5. Closely-Spaced Motorcycles

3.2 Further Explanation of Class 14 Under the MINN6 Scheme

Once the main issue with Class 14 under the MINN6 scheme was understood to be that multi-unit trucks were being broken into two records, 65 Class 14 records were analyzed. These records were the subset of the Class 14s that had a clear image of the vehicle rather than the complete set of Class 14s that included nighttime images that could not be deciphered.

- 82 percent showed back of a 5-axle semi
- 12 percent were semis straddling the lane line
- 3 percent were pickups with horse trailer or camper (5th wheel)
- 3 percent were passenger cars – class 2

Of the semi-trucks, the issue is that the truck is being split into a class 6 and class 14 record. Thus, the quantity of class 14s could be added to the class 9s and should also be subtracted from the class 6 quantity.

3.3 Changes to the WIM Classification Scheme

This section describes the recommended changes that may improve the current WIM scheme. An explanation for each bin is provided. The methodology assumes that the first differentiating factor between vehicles is the axle count. The recommendations are organized as follows:

- Two axles
  - Classes 1, 2, 3, 4, 5
- Three axles
  - Classes 1, 2, 3, 4, 6, 8
- Four axles
  - Classes 2, 3, 4, 7, 8
- Five axles and greater

Section 3.5 includes a results summary table that compares the MINN6 classifications to the Revised WIM classifications.

3.3.1 Two-Axle Vehicles

Axle weight and gross vehicle weight improves two-axle vehicle classification considerably. The front axle weight is the best determinate of the vehicle class. Below are the recommended changes for the two-axle WIM criteria.

Two Axles – Class 1 (Motorcycles)

The current WIM scheme for classifying motorcycles as class 1 provides an axle spacing upper limit of 4.9 feet. However, many motorcycles have axle spacings greater than five feet. For example, from 2 pm to 3 pm on April 22, 2012, 22 motorcycles were recorded, but 15 of them were misclassified as class 2 because their wheelbases were longer than 4.9 feet. In contrast, the ATR scheme has a wider axle spacing of 5.9 feet and would have classified all of these vehicles correctly based on axle spacing alone.

Therefore, the ATR "Spacing 1" criteria of 1.0 feet to 5.9 feet was applied in the revised WIM scheme. The maximum weights are also increased to 10 kips to account for the large variation in motorcycle weights observed. The minimum axle weights were reduced to 0.4 kips to be able to classify light motorcycles and drivers. This lower limit was determined by examining records that MINN6 classified as motorcycles. Of 221 records, only one was lower than 0.4 kips. MINN6 does not have a lower limit for axle weight for this class. An example of a previously misclassified motorcycle that will be properly classified with the recommended scheme is shown below in Table 3.2 and Figure 3.3.

Table 3.3. Two Axles – Class 1 (Motorcycles) Classifications

Scheme	Spacing 1	Axle Weight 1	Axle Weight 2	GVW
MINN6	0.0 – 4.9	0 – 2	0 – 3	0 – 5
ATR	0.0 – 5.9			
Revised WIM	1.0 – 5.9	0.4 – 10	0.4 – 10	0.5 – 10

Figure 3.6. Example Motorcycle Misclassification

Two Axles – Class 2 (Passenger Cars)

For class 2, the WIM scheme was brought in line with the MnDOT ATR Scheme. Currently the automobile with the smallest wheelbase is the Smart ForTwo with an axle spacing of six feet. To accommodate this vehicle and align with the two-axle class 1 criteria, the lower bound of the axle spacing was set at 5.9 feet. Table 3.3 illustrates this adjustment.

Table 3.4. Two Axles – Class 2 Classifications

Scheme	Spacing 1	Axle Weight 1	Axle Weight 2	GVW
MINN6 Scheme	5.0 – 9.8	0 – 4	0 – 5	0 – 9
ATR	6.0 – 10.0			
Revised WIM	5.9 – 10.0	0.5 – 4	0.5 – 5	1 – 9

Two Axles – Class 3 (Pickup Trucks and Panel Vans)

The MINN6 class 2 and class 3 had overlapping wheelbases and axle weights. Differentiating these vehicles based on front axle weight improves classification. As shown in Table 3.4, vehicles with "Spacing 1" of 10 feet or less are classified as class 3 if "Axle Weight 1" is between 4 and 10 kips. The upper bound of "Spacing 1" was increased to 14.5 feet to account for extended cab pickup trucks that can fall between 13.6 feet and 14.5 feet.

Note: The notation "Revised WIM-A" and "Revised WIM-B" denotes that these are two separate bins within the revised WIM scheme. Further analysis in this section also uses this notation.

Table 3.5 Two Axles Class 3 Classifications

Scheme	Spacing 1	Axle Weight 1	Axle Weight 2	GVW
MINN6	5.0 – 13.8	0 – 5	0 – 7	0 – 11
ATR	10.1 – 13.6			
Revised WIM–A	6.0 – 10.0	4 – 10	0.5 – 7	4 – 11
Revised WIM–B	10.0 – 14.5	0.5 – 5	0.5 – 7	3 – 11

Two Axles – Class 4 (Buses)

The ATR scheme was used for the spacing and the WIM scheme was used for axle weight in the revised class 4 scheme, see Table 3.5.

Table 3.6. Two Axles Class 4 Classifications

Scheme	Spacing 1	Axle Weight 1	Axle Weight 2	GVW
MINN6	24.0 – 41.5	3 – 20	0 – 40	0 – 60
ATR	24.0 – 40.0			
Revised WIM	24.0 – 40.0	3 – 20	1 – 40	3 – 60

Two Axles – Class 5 (Two-Axle Single-Unit Trucks)

The class 5 scheme two-axle scheme was broken into two bins. The first bin collects small class 5 vehicles with “Spacing 1” of 10.0 to 14.5 feet, but filters out class 3 vehicles using the weight criteria. The second bin captures long wheelbase class 5 vehicles.

Table 3.7. Two Axles – Class 5 Classifications

Scheme	Spacing 1	Axle Weight 1	Axle Weight 2	GVW
MINN6	6.9 – 24.0	3 – 20	0 – 40	0 – 60
ATR	13.7 – 24.0			
Revised WIM–A	10.0 – 14.5	5 – 20	1 – 40	5 – 60
Revised WIM–B	14.5 – 24.0	1 – 20	1 – 40	5 – 60

3.3.2 Three-Axle Vehicles

Small vehicles (motorcycles, automobiles, and pickup trucks) frequently carry single-axle trailers. Because the length of the trailer is usually independent of the class of vehicle, the same classification principles used for two-axle vehicles should be applied to many three-axle schemes. Buses and single unit trucks also commonly have three axles, but are relatively easy to differentiate from two axle vehicles with trailers based on axle spacing.

Three Axles – Class 1 (Motorcycles)

The spacing from the ATR scheme and the axle weights from MINN6 were used to create the Revised WIM, see Table 3.7.

Table 3.8. Three Axles – Class 1 (Motorcycles) Classifications

Scheme	Spacing 1	Spacing 2	Axle Weight 1	Axle Weight 2	Axle Weight 3	GVW
MINN6	0.0 – 4.9	0.0 – 8.0	0 – 2	0 – 3	0 – 3	0 – 8
ATR	1.0 – 5.9	1.0 – 7.9				
Revised WIM	1.0 – 5.9	1.0 – 7.9	0.5 – 2	0.5 – 3	0.5 – 3	0.5 – 8

Three Axles – Class 2 (Passenger Cars)

The “Spacing 1” of class 2 two-axle vehicles was applied. “Spacing 2” from the ATR scheme and the axle weights from MINN6 were used to create the Revised WIM, see Table 3.8.

Table 3.9. Three Axles – Class 2 (Passenger Cars) Classifications

Scheme	Spacing 1	Spacing 2	Axle Weight 1	Axle Weight 2	Axle Weight 3	GVW
MINN6	5.0 – 9.8	4.0 – 24.0	0 – 4	0 – 5	0 – 7	0 – 17
ATR	6.0–10.0	3.0–20.0				
Revised WIM	5.9 – 10.0	3.0 – 20.0	0.5 – 4	0.5 – 5	0.5 – 7	1 – 17

Three Axles – Class 3 (Pickup Trucks and Vans)

The “Spacing 1” of class 3 two axle vehicles was used as the “Spacing 1” for class 3 three axle vehicles. The “Spacing 2” is the same as the ATR scheme. “Axle Weight 1” ranges from four to eight kips to differentiate pickups with trailers from automobiles with trailers and class 6 trucks. The Revised WIM-B bin allows for pickups with longer wheel bases, but lower weights compared to single unit trucks to be classified properly.

Table 3.10. Three Axles – Class 3 (Pickup Trucks and Vans)

Scheme	Spacing 1	Spacing 2	Axle Weight 1	Axle Weight 2	Axle Weight 3	GVW
MINN6	5.0 – 13.8	4.0 – 40.0	0 – 5	0 – 7	0 – 7	0 – 18
ATR	10.1 – 13.6	6.0 – 22.0				
Revised WIM-A	6.0 – 10.0	6.0 – 22.0	4 – 8	0.5 – 7	0.5 – 7	4 – 18
Revised WIM-B	10.0 – 14.5	6.0 – 22.0	0.5 – 8	0.5 – 7	0.5 – 7	3 – 18

Three Axles – Class 4 (Buses)

A new articulated bus used by Metro Transit manufactured by New Flyer, did not fall into one of the ATR bins, therefore “Spacing 2” for the Revised WIM-A scheme was increased to 20.0 to 30.0 feet. This change also mitigated the problem of class 5 vehicles with trailers falling into a class 4 bin. The lower bound for “Spacing 1” in Revised WIM-A was increased to 16 feet to avoid overlap with class 8. An edited version of the ATR-A spacing was used for the Revised WIM-A bin. Revised WIM-B allows for a single unit bus with a long wheelbase as shown in Table 3.10.

Table 3.11. Three Axles – Class 4 (Buses)

Scheme	Spacing 1	Spacing 2	Axle Weight 1	Axle Weight 2	Axle Weight 3	GVW
MINN6-A	24.0 – 41.5	2.0 – 10.0	3 – 20	0 – 40	0 – 40	0 – 100
MINN6-B	24.0 – 41.5	6.0 – 29.0	3 – 20	0 – 40	0 – 40	0 – 100
MINN6-C	13.6 – 41.5	0.0 – 41.5	3 – 20	0 – 40	0 – 40	0 – 100
ATR – A	13.7 – 24.0	6.0 – 20.0				
ATR – B	24.0 – 40.0	3.0 – 40.0				
Revised WIM-A	16.0 – 24.0	20.0 – 30.0	3 – 20	1 – 40	1 – 40	3 – 100
Revised WIM-B	24.0 – 40.0	3.0 – 40.0	3 – 20	1 – 40	1 – 40	3 – 100

Three Axles – Class 6

The spacing from the ATR scheme and the weights from MINN6 are combined to create the Revised WIM scheme as shown in Table 3.11.

Table 3.12. Three Axles – Class 6 Classifications

Scheme	Spacing 1	Spacing 2	Axle Weight 1	Axle Weight 2	Axle Weight 3	GVW
MINN6	6.0–40.0	0.0–10.7	3–25	0–40	0–40	0–105
ATR	10.1–22.1	2.0–5.9				
Revised WIM	10.1–22.1	2.0–6.0	3–25	1–40	1–40	10–105

Three Axles – Class 8 (Four-Axle Multi-Unit Trucks)

The "Spacing 2" criteria for Revised WIM-A scheme differs from the ATR scheme, which has a lower bound of 22 feet. Commonly, class 8 trucks have a "Spacing 2" of 20 to 21 feet. One is shown in Figure 3.4. By increasing the lower bound of "Axle Weight 1" from three kips to eight kips, some pickups carrying two axle trailers are filtered out. A previously misclassified pickup is shown in Figure 3.5.

The upper bound of "Spacing 1" of Revised WIM was decreased to 16.0 feet to avoid overlap with class 4 vehicles. Almost all three-axle class 8 trucks have a "Spacing 1" of less than 16 feet, although Revised WIM-C is provided to catch those outside this range. The scheme is shown in Table 3.12.

Table 3.13. Three Axles – Class 8 (Four-Axle Multi-Unit Trucks) Classifications

Scheme	Spacing 1	Spacing 2	Axle Weight 1	Axle Weight 2	Axle Weight 3	GVW
MINN6	6.0 – 24.0	8.0 – 41.5	3 – 20	0 – 40	0 – 40	0 – 100
ATR	9.0 – 24.0	22.0 – 40.0				
Revised WIM-A	9.0 – 16.0	20.0 – 41.5	8 – 20	1 – 40	1 – 40	10 – 100
Revised WIM-B	10.0 – 14.5	4.0 – 40.0	5 – 20	1 – 40	1 – 40	10 – 100
Revised WIM-C	14.5 – 24.0	4.0 – 20.0	1 – 20	1 – 40	1 – 40	10 – 100

Figure 3.7. Correctly Classified Semi-Trailer Truck

Figure 3.8. Incorrectly Classified Pickup with Trailer

3.3.3 Four-Axle Vehicles

Four-axle vehicles can be difficult to properly classify because there is a large range of vehicles that fall under the four-axle vehicle classification. Examples of common four-axle vehicles include passenger cars with two-axle light trailers and concrete mixing transport trucks.

Four Axles – Class 2 (Passenger Cars)

The axle spacing was matched to the ATR scheme and the weights from MINN6 scheme were used to create the Revised WIM classification scheme shown in Table 3.13.

Table 3.14. Four Axles – Class 2 (Passenger Cars) Classifications

Scheme	Spacing 1	Spacing 2	Spacing 3	Axle Weight 1	Axle Weight 2	Axle Weight 3	Axle Weight 4	GVW
MINN6	5.0 – 9.8	1.0 – 24.0	1.0 – 20.1	0 – 4	0 – 5	0 – 5	0 – 5	0 – 18
ATR	1.0 – 10.0	6.0 – 20.0	1.0 – 20.0					
Revised WIM	1.0 – 10.0	6.0 – 20.0	1.0 – 20.0	0.5 – 4	0.5 – 5	0.5 – 5	0.5 – 5	1 – 18

Four Axles – Class 3 (Pickup Trucks and Vans)

The spacing from the ATR scheme and the weights from the MINN6 were incorporated and aligned with the criteria for three axle vehicles. The revised WIM-A accounts for passenger vehicles with light trailers. The revised WIM-B accounts for light pickup trucks with light trailers as shown in Table 3.14.

Table 3.15. Four Axles – Class 3 (Pickup Trucks and Vans) Classifications

Scheme	Spacing 1	Spacing 2	Spacing 3	Axle Weight 1	Axle Weight 2	Axle Weight 3	Axle Weight 4	GVW
MINN6	5.0 – 14.3	1.0 – 40.0	1.0 – 20.1	0 – 5	0 – 13	13	0 – 13	0 – 45
ATR	10.1 – 13.6	6.0 – 25.0	1.0 – 20.0					
Revised WIM-A	6.0 – 10.0	6.0 – 40.0	1.0 – 20.0	4 – 8	0.5 – 7	0.5 – 7	0.5 – 13	3 – 45
Revised WIM-B	10.0 – 14.5	6.0 – 40.0	1.0 – 20.0	0 – 8	0.5– 7	0.5 – 7	0.5 – 13	3 – 45

Four Axles – Class 4 (Buses)

Class 4, four axle vehicles were broken into various groupings by the MINN6 scheme and ATR scheme. These differences account for tandem axles or tridem rear axles. The ATR “Spacing 1” was increased to catch the larger semis. This change was necessary to avoid class 4 and class 8 overlap.

The Revised WIM-C shown below has “Spacing 1” altered from the ATR scheme. Also there was a need to account for four axle busses with both front and rear tandem axles, see Table 3.15.

Table 3.16. Four Axles – Class 4 (Buses) Classifications

Scheme	Spacing 1	Spacing 2	Spacing 3	Axle Weight 1	Axle Weight 2	Axle Weight 3	Axle Weight 4	GVW
MINN6 A	6.0 – 24.0	2.0 – 10.0	3.0 – 24.0	3 – 40	0 – 40	0 – 40	0 – 40	0 – 160
MINN6 B	9.0 – 24.0	8.0 – 41.5	0.00 – 10.0	3 – 40	0 – 40	0 – 40	0 – 40	0 – 160
ATR A	10.1 – 24.0	2.0 – 5.9	8.1 – 20.0					
ATR B	24.0 – 40.0	2.0 – 40.0	1.0 – 40.0					
ATR C	13.7 – 22.1	6.0 – 30.0	1.0 – 20.0					
Revised WIM-A	10.0 – 24.0	2.0 – 6.0	8.0 – 20.0	3 – 40	1 – 40	1 – 40	1 – 40	3 – 160
Revised WIM-B	24.0 – 40.0	2.0 – 40.0	1.0 – 40.0	3 – 40	1 – 40	1 – 40	1 – 40	3 – 160
Revised WIM-C	2.0 – 11.0	6.0 – 30.0	1.0 – 20.0	3 – 40	1 – 40	1 – 40	1 – 40	3 – 160

The Revised WIM scheme fixes misclassifications such as the class 7 truck being classified as a class 4 as shown in Figure 3.6.

Figure 3.9. Class 7 Truck Misclassified as Class 4

Four Axles – Class 7 (4+ Axle Single-Unit Trucks)

The MINN6 scheme of four axle class 7 vehicles contained too many four-axle vehicles. This bin was eliminated to avoid overlap between classes. The revised bin uses the ATR scheme's axle spacing and implements an open weight configuration. The scheme is shown in Table 3.16.

Table 3.17. Four Axles – Class 7 (4+ Axle Single-Unit Trucks) Classifications

Scheme	Spacing 1	Spacing 2	Spacing 3	Axle Weight 1	Axle Weight 2	Axle Weight 3	Axle Weight 4	GVW
MINN6-A	6.0 – 29.0	2.0 – 8.0	2.0 – 8.0	3 – 20	0 – 40	0 – 40	0 – 40	3 – 92
MINN6-B	0.0 – 24.0	0.0 – 41.5	0.0 – 41.5	3 – 22	0 – 40	0 – 40	0 – 40	0 – 142
ATR	6.0 – 22.1	1.0 – 5.9	1.0 – 8.0					
Revised WIM	6.0 – 22.1	1.0 – 6.0	1.0 – 8.0	3 – 22	1 – 40	1 – 40	1 – 40	3 – 142

Four Axles – Class 8 (Four-Axle Multi-Unit Trucks)

The upper boundary of "Spacing 1" for Revised WIM-B was increased to 24.0 feet to allow larger class 8 semi-trailer trucks to be correctly classified. Because short class 8 vehicles overlap with pickups hauling two wheel trailers, the lower bound of "Axle Weight 1" was increased to 8 kips to differentiate the two classes as shown in Table 3.17.

Table 3.18. Four Axles – Class 8 (Four-Axle Multi-Unit Trucks) Classifications

Scheme	Spacing 1	Spacing 2	Spacing 3	Axle Weight 1	Axle Weight 2	Axle Weight 3	Axle Weight 4	GVW
MINN6-A	6.0 – 29.0	2.0 – 10.0	6.0 – 50.9	3 – 40	0 – 40	0 – 40	0 – 40	0 – 160
MINN6-B	6.0 – 29.0	8.0 – 41.5	2.0 – 10.0	3 – 40	0 – 40	0 – 40	0 – 40	0 – 160
ATR-A	11.0 – 13.7	20.1 – 40.0	3.4 – 8.0					
ATR-B	11.0 – 13.7	1.0 – 5.9	20.1 – 40.0					
Revised WIM-A	11.0 – 14.0	20.0 – 40.0	3.4 – 8.0	8 – 40	1 – 40	1 – 40	1 – 40	10 – 160
Revised WIM-B	11.0 – 24.0	1.0 – 5.9	20.0 – 40.0	3 – 40	1 – 40	1 – 40	1 – 40	10 – 160

3.3.4 Greater Than Four-Axle Vehicles

Vehicles with more than four axles have relatively standard axle spacing. Also, due to the long axle spacing, there is almost always enough information for vehicles to be classified strictly based on axle spacing. For these reasons, weight is not a strong factor in classifying these vehicles and the "tried and true" ATR scheme should be adopted. The weight for any one vehicle can vary dramatically depending on its load.

3.4 Revised Weigh-in-Motion Classification Table

The revised WIM scheme is provided in Appendix A. The ATR scheme can be derived by excluding the weight information. For bins that have overlapping axle spacing, the classifier should accept the topmost bin for which the axle spacing criteria matches.

Chapter 4. Conclusions and Next Steps

This report summarizes recommended changes to MnDOT’s WIM scheme. As with all general purpose automated detection and classification, the recommended scheme will not perfectly classify every vehicle. External factors, such as sensor error, lane changes, non-standard vehicles, and overlap between classes, are outside the control of what a tuned classification scheme can provide. However, this effort aimed to improve the classification accuracy over the scheme and unify the ATR scheme with the WIM scheme. Future analysis is recommended to test whether the revised scheme classifies vehicles more accurately than the MINN6 scheme.

Weigh-in-motion classification schemes use more information than axle-only schemes and can therefore better differentiate vehicles with two to four axles. Weight data helps differentiate vehicles with similar axle spacing combinations. Vehicles with more than four axles are easily differentiated based on axle spacing alone.

The Revised WIM scheme presented in this report was verified with anecdotal checks against WIM records with images. A future effort could do a statistically significant analysis of which classification scheme classifies more vehicles that match manually determined classifications.

Appendix A. Revised Weigh-in-Motion Classification Scheme Table

Table A19. Revised Weigh-in-Motion Classification Scheme

Vehicle Description	Class	No. of Axles	Spacing 1 (feet)	Spacing 2 (feet)	Spacing 3 (feet)	Spacing 4 (feet)	Axle 1 Weight (kips)	Axle 2 Weight (kips)	Axle 3 Weight (kips)	Axle 4 Weight (kips)	Axle 5 Weight (kips)	Gross Vehicle Weight (kips)
Passenger Car (Default for 0-Axle)	2	0	0.0 to 0.0									0 to 0
Passenger Car (Default for 1-Axle)	2	1	0.0 to 0.0				0 to 5					0 to 5
Motorcycle	1	2	1.0 to 5.9				0.4 to 10	0.4 to 10				0.8 to 10
Passenger Car	2	2	5.9 to 10.0				0.5 to 4	0.5 to 5				1 to 9
Other (Pickup/Van)	3	2	10.0 to 14.5				0.5 to 5	0.5 to 7				3 to 11
Other (Pickup/Van, Short, Heavy Ax1)	3	2	6.0 to 10.0				4 to 10	0.5 to 7				4 to 11
Bus (2-axle)	4	2	24.0 to 40.0				3 to 20	0.5 to 40				3 to 60
2D Single Unit (regular)	5	2	14.5 to 24.0				5 to 20	0.5 to 40				5 to 60
2D Single Unit (Short, Heavy Ax1)	5	2	10.0 to 14.5				5 to 20	0.5 to 40				5 to 60
Motorcycle w/Trailer	1	3	1.0 to 5.9	1.0 to 7.9			0.5 to 2	0.5 to 3	0.5 to 3			0.5 to 8
Car w/1 Axle Trailer	2	3	5.9 to 10.0	3.0 to 20.0			0.5 to 4	0.5 to 5	0.5 to 7			1 to 17
Other (Pickup/Van) w/1-Axle Trailer	3	3	10.0 to 14.5	6.0 to 22.0			0.5 to 8	0.5 to 7	0.5 to 7			3 to 18
Other (Pickup/Van) w/1-Axle Trailer (Heavy Ax1)	3	3	6.0 to 10.0	6.0 to 22.0			4 to 8	0.5 to 7	0.5 to 7			4 to 18
Bus (3-Axle, Regular)	4	3	24.0 to 40.0	3.0 to 40.0			3 to 20	1 to 40	1 to 40			3 to 100
Bus (3-Axle, Short)	4	3	16.0 to 24.0	20.0 to 30.0			3 to 20	1 to 40	1 to 40			3 to 100
3-Axle Single Unit	6	3	10.1 to 22.1	2.0 to 6.0			3 to 25	1 to 40	1 to 40			10 to 105
Semi, 2S1	8	3	9.0 to 16.0	20.0 to 41.5			8 to 20	1 to 40	1 to 40			10 to 100
Class 5 (Short) with trailer	8	3	10.0 to 14.5	4.0 to 40.0			5 to 20	1 to 40	1 to 40			10 to 100
Class 5 w/ Trailer (long)	8	3	14.5 to 24.0	4.0 to 20.0			0 to 20	1 to 40	1 to 40			10 to 100
Car w/2-Axle Trailer	2	4	1.0 to 10.0	6.0 to 20.0	1.0 to 20.0		0 to 4	0.5 to 5	0.5 to 5	0.5 to 5		1 to 18
Other (Pickup/Van) w/2-Axle Trailer	3	4	10.0 to 14.5	6.0 to 40.0	1.0 to 20.0		0 to 8	0.5 to 7	0.5 to 7	0.5 to 13		3 to 45
Small (Pickup/Van) w/2-Axle Trailer	3	4	6.0 to 10.0	6.0 to 40.0	1.0 to 20.0		4 to 8	0.5 to 7	0.5 to 7	0.5 to 13		3 to 45
3-Axle Single Unit w/1-Axle Trailer	4	4	10.0 to 24.0	2.0 to 6.0	8.0 to 20.0		3 to 40	1 to 40	1 to 40	1 to 40		3 to 160
2/3-Axle Single Unit w/ 1/2-Axle Trailer	4	4	2.0 to 11.0	6.0 to 30.0	1.0 to 20.0		3 to 40	1 to 40	1 to 40	1 to 40		3 to 160
Default Single Unit Truck- Trailer Combination	4	4	24.0 to 40.0	2.0 to 40.0	1.0 to 40.0		3 to 40	1 to 40	1 to 40	1 to 40		3 to 160
4-Axle Single Unit	7	4	6.0 to 22.1	1.0 to 6.0	1.0 to 8.0		3 to 22	1 to 40	1 to 40	1 to 40		3 to 142
Semi, 3S1	8	4	11.0 to 24.0	1.0 to 5.9	20.0 to 40.0		3 to 40	1 to 40	1 to 40	1 to 40		10 to 160
Semi, 2S2	8	4	11.0 to 14.0	20.0 to 40.0	3.4 to 8.0		8 to 40	1 to 40	1 to 40	1 to 40		10 to 160
Other (Pickup/Van) w/3-Axle Trailer	3	5	6.0 to 13.6	6.0 to 25.0	1.0 to 2.9	1.0 to 2.9	1 to 5	1 to 13	1 to 13	1 to 13	1 to 13	3 to 58
3-Axle Single Unit w/2-Axle Trailer	4	5	6.0 to 22.1	1.0 to 5.9	6.0 to 11.0	3.0 to 8.0	3 to 20	1 to 25	1 to 25	1 to 25	1 to 25	3 to 121
5-Axle Single Unit (Short Spacing 4)	7	5	6.0 to 19.5	1.0 to 5.9	3.0 to 5.9	3.0 to 8.0	3 to 20	1 to 25	1 to 25	1 to 25	1 to 25	3 to 120
5-Axle Single Unit (Long Spacing 4)	7	5	10.1 to 22.1	1.0 to 5.9	1.0 to 8.0	8.1 to 20.0	3 to 20	1 to 25	1 to 25	1 to 25	1 to 25	3 to 120
Semi (3S2 or 2S3)	9	5	6.0 to 25.0	3.0 to 5.9	11.1 to 45.0	3.0 to 15.0	3 to 40	1 to 40	1 to 40	1 to 40	1 to 40	3 to 214
Semi (2S3)	9	5	6.0 to 19.5	6.0 to 40.0	3.0 to 8.0	3.0 to 8.0	3 to 40	1 to 40	1 to 40	1 to 40	1 to 40	3 to 214
Twin Trailer Semi	11	5	6.0 to 19.5	15.1 to 25.0	6.0 to 20.0	15.1 to 25.0	3 to 25	1 to 25	1 to 25	1 to 25	1 to 25	3 to 125

Table A20. Revised Weigh-in-Motion Classification Scheme (continued)

	Class	No. of Axles	Spacing 1 (feet)	Spacing 2 (feet)	Spacing 3 (feet)	Spacing 4 (feet)	Spacing 5 (feet)	Spacing 6 (feet)	Spacing 7 (feet)	Axle 1 Weight (kips)	Axle 2 Weight (kips)	Axle 3 Weight (kips)	Axle 4 Weight (kips)	Axle 5 Weight (kips)	Axle 6 Weight (kips)	Axle 7 Weight (kips)	Axle 8 Weight (kips)	Gross Vehicle Weight (kips)
3-Axle Single Unit w/3-Axle Trailer	4	6	6.0 to 22.1	1.0 to 5.9	1.0 to 25.0	8.0 to 25.0	1.0 to 20.0			3 to 40	1 to 40	1 to 40	1 to 40	1 to 40	1 to 40			3 to 238
3-Axle Single Unit w/Tridem Trailer	4	6	10.1 to 22.1	2.0 to 5.0	8.1 to 18.2	2.0 to 5.0	2.0 to 5.0			3 to 40	1 to 40	1 to 40	1 to 40	1 to 40	1 to 40			3 to 238
6-Axle Single Unit	7	6	6.0 to 22.1	1.0 to 5.9	1.0 to 8.0	1.0 to 8.0	1.0 to 8.0			1 to 40	1 to 40	1 to 40	1 to 40	1 to 40	1 to 40			3 to 145
Semi 3S3	10	6	6.0 to 25.0	3.0 to 6.0	18.2 to 40.0	3.0 to 15.0	3.0 to 8.0			3 to 40	1 to 40	1 to 40	1 to 40	1 to 40	1 to 40			10 to 238
Semi+FullTrailer, 3S12	12	6	1.0 to 40.0	1.0 to 40.0	1.0 to 40.0	1.0 to 40.0	1.0 to 40.0			3 to 40	1 to 40	1 to 40	1 to 40	1 to 40	1 to 40			10 to 238
7-Axle Single Unit	7	7	6.0 to 19.5	1.0 to 5.9	1.0 to 8.0	1.0 to 8.0	1.0 to 8.0	1.0 to 8.0		3 to 25	1 to 40	1 to 40	1 to 40	1 to 40	1 to 40	1 to 40		10 to 265
Truck (3S4 or 4S3)	10	7	6.0 to 25.0	3.0 to 6.0	8.0 to 45.0	3.0 to 15.0	3.0 to 8.0	3.0 to 8.0		3 to 25	1 to 40	1 to 40	1 to 40	1 to 40	1 to 40	1 to 40		10 to 265
7-Axle Multi Unit	13	7+	0.0 to 40.0	1.0 to 8.0	8.0 to 40.0	1.0 to 8.0	8.0 to 40.0	8.1 to 40.0		3 to 25	1 to 40	1 to 40	1 to 40	1 to 40	1 to 40	1 to 40		10 to 280