Commercial Vehicle Loading in an Urban Environment

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ABSTRACT

Increasing commercial vehicle operations on highways is resulting in increased structural depreciation of our road infrastructure assets. This increase in commercial trucking is also increasing truck loading on urban pavements. By actively monitoring and quantifying commercial truck loadings and reducing the amount of overloading, it may be possible to better design and extend the life of road and bridge structures.

Many State and Provincial transportation departments have extensive traffic data collection and commercial vehicle enforcement programs in place. Urban municipalities have typically not implemented programs of this type to a comparable level and therefore have not realized the benefits of these programs. However, commercial traffic flow is often more concentrated and may include stop and go conditions. Therefore commercial vehicles in an urban environment can significantly increase the damage inflicted onto urban roads compared to rural roads.

This paper presents the pilot implementation of a weigh in motion (WIM) and video surveillance system installed in Saskatoon, SK. Specifically this paper presents commercial vehicle loading data collected in an urban environment, quantifies overloading that is occurring, the effects this overloading is having on the roadway infrastructure, and what can be done to reduce the overloading. Using data from a recently installed WIM system with video capture capabilities commercial vehicle traffic types and volumes were quantified with regards to time of day, day of week, percent trucks overloaded, and severity of overloading. The use of the WIM system as a tool for enhancing traffic data collection and commercial vehicle enforcement in an urban environment is examined.

The analysis showed that for the study period, 2.2 percent of commercial vehicles exceeded the allowable gross vehicle weight and 12.8 percent of commercial vehicles exceeded one or more of the axle, axle group, and gross vehicle weight limits. Overloading was most common on weekdays and during the working day. The types of vehicles most likely to be in violation of weight limits were the seven and eight axle combination units. However, when roadway loading due to excess weight was considered, the greatest contribution to excess loading came from the class with two and three axle trucks. These are typically local service vehicles that operate within the vicinity of the city and are generally not subjected to inspection at fixed weigh stations to the same level as larger trucks used for long-haul operations.

COMMERCIAL VEHICLE LOADING IN AN URBAN ENVIRONMENT

INTRODUCTION

While State and Provincial road agencies often have extensive traffic data collection and weight enforcement programs in place, including weigh in motion (WIM), urban municipalities have typically not implemented programs of this type. Because commercial traffic weight data collection is not typically performed in cities, the city may be unaware of commercial vehicle loadings and specifically how much commercial vehicle overloading is taking place on its urban streets. Therefore, the lack of available data may hinder efforts to effectively plan, design, monitor and evaluate performance of the highway infrastructure.

Monitoring and preventing overloading is of great importance to those responsible for the maintenance and operation of highway infrastructures. The additional weight carried by overloaded trucks accelerates the deterioration of the roadway, leading to rutting, fatigue, and in some cases structural failure. In a 1990 report (1), illegally loaded trucks were estimated to cost United States taxpayers \$160 to \$670 million per year on the highway system.

It has been shown that there is a correlation between the intensity of enforcement activity and the amount of overloading that occurs, with increased enforcement intensity resulting in reduced overloading (2, 3). The relationship between enforcement and overloading is affected by a number of factors including the type of enforcement (i.e. permanent station vs. mobile operation), the penalty and fine structure, and inspection rate (4). The lower level of enforcement typically found in the urban setting suggests that more frequent overloading should be expected. While the urban highway infrastructure is subject to accelerated deterioration due to overloading, the municipality may be even more significantly impacted when these overloaded trucks use local streets which have a lesser structural design and even a single pass can inflict serious damage.

Accurate traffic information is an important component in the planning, design, and evaluation of road infrastructure. WIM systems can provide the necessary information for these tasks. Knowing the expected traffic loading is a design parameter that will determine the materials and structure used in construction. To evaluate the performance of pavement designs in the field details of the actual traffic loading to which roadway sections are exposed are required.

This paper examines the traffic loading data obtained from a WIM site on an urban freeway in Saskatoon, Canada. WIM systems are typically used in one of two applications, data collection and vehicle pre-screening at weight enforcement facilities. The WIM system collects individual axle weights, spacing between axles, and speed for each vehicle and uses this information to determine axle group weights, gross vehicle weight and vehicle classification. Depending on the application, each vehicle record may be examined in detail, or data may be considered as it represents the total traffic flow. In this study, the WIM system was used to determine the magnitude and characteristics of overloading including the number, severity, and timing of overloading and the types of vehicles responsible. The application of the WIM system installed in an urban setting for planning, design and preservation as well providing a tool for increasing enforcement efficiency is discussed.

SITE DESCRIPTION

The WIM system used in this study is located in the two northbound lanes of Circle Drive, an urban freeway, in the south-eastern part of Saskatoon as illustrated in Figure 1. Circle Drive is a grade-separated freeway with a posted speed limit of 90 km/hr. Circle Drive is one of two truck routes for truck traffic through the city as well as a key arterial for intracity traffic. The alternate truck route through Saskatoon for trucks coming from the southeast leads through the downtown area and therefore is not a desirable route for much of the through traffic.

Two of the main highways that serve the south side of Saskatoon are Highway 16, also known as the Yellowhead, which is a main east-west trade corridor through western Canada, and Highway 11 which is a connecting highway from the city of Regina.

VIDEO WIM TECHNOLOGY

The equipment installed at this site includes two WIM technologies, a load cell scale in the right lane, where the majority of the truck traffic is expected to travel, and a quartz axle sensor array in the left lane. A video image capture system is also installed at the site. Figure 2 provides a picture of the monitoring camera installation at the site and a typical load cell scale installation. The load cell scale meets the Type III accuracy requirements (+/- 6 percent on GVW, 95 percent confidence) as defined for WIM applications by the American Society for Testing and Materials (ASTM) E1318-00). The quartz axle sensor array provides WIM data with accuracy as specified by ASTM E1318-00 Type I (+/- 10 percent on GVW, 95 percent confidence) (5). The data recorded from the WIM equipment includes individual axle, axle group, and gross vehicle weights, axle spacing, and vehicle speed.

The video camera and video image capture card capture an image of every commercial vehicle crossing the WIM installation. The image is correlated to the vehicle weight record and stored together. The data file can be retrieved at any time and the records viewed to see what types of trucks are using the freeway and whether they are complying with specified weights and dimensions regulations.

The video information can also be viewed in real-time using a web-based application. A web-site address has been provided that links a user with appropriate access provisions directly to the road-side computer. When connected to the web-site, the user can view the image and vehicle record, including axle weight and separation, of each truck as they pass the site and select particular trucks based on time or sequence number for detailed examination. Access can be gained from a variety of internet capable devices including some hand-held personal digital assistants.

COMMERCIAL TRAFFIC LOADING PATTERNS AND PROFILES

Prior to the installation of the WIM system there was no comprehensive and continuous data available that could be used to quantify continuous traffic conditions and to quantify overloading if present. With the installation of the WIM, the analysis evaluates overweight vehicles, which in this context is defined as any vehicle that exceeds the normal allowable weight for that category of vehicle. In the analysis no distinction is made between trucks that may be legally overweight due to permits or exemptions, and those that are illegally overweight. The discussion includes overweight vehicles in two categories, those that exceed the allowable GVW are labelled as “GVW Limits”, while those that exceed one or more of the applicable axle, axle group, or GVW limits are labelled as “Axle or GVW Limits”.

Data Collection and Traffic Characterization

Data was collected from the site during a one week period from September 4th to 10th, 2002, a time period that did not include a long weekend or any holidays. For the chosen time period primary allowable weight limits were in effect.

Weights and dimensions regulations in effect on this roadway segment were applied to determine the characteristics of commercial vehicle weights. The classification scheme used by Saskatchewan Highways and Transportation was used to determine maximum allowable weight limits by vehicle type. Approximately 5000 vehicle records were compiled and analyzed, with each vehicle record including individual axle weights, spacing between axles, and vehicle speed. The range of vehicles covered was from two axle single units, Federal Highway Authority (FHWA) Class 5, up to eight axle multiple trailer units, FHWA Class 13. Configurations of nine axles or more are only allowed by permit and account for approximately one percent of the commercial vehicle stream. These vehicles were excluded from the analysis since the allowable weight varies depending on the permit issued, so determination of excess loading is not possible without knowing the specific permit for each vehicle.

For analysis purposes, the truck population observed on Circle Drive was divided into five representative categories as follows:

- FHWA Class 9: Five axle semi-trailer
- FHWA Class 10: Six axle semi-trailer
- FHWA Class 13A: Seven axle combination unit
- FHWA Class 13B: Eight axle combination unit
- Other: All other trucks, 85 percent of which are two and three axle single units

The percentage of each truck type is illustrated in Figure 3 and summarized in Table 1 along with other vehicle class specific information. Over 40 percent of the trucks observed on Circle Drive were Class 9, with approximately 20 percent of trucks in each of the Classes 10, 13B, and other categories. The remaining two percent of the trucks observed on Circle Drive were Class 13A.

Temporal Distribution of Commercial Traffic

One area of examination that will help to define commercial vehicle traffic patterns is the temporal occurrence of truck traffic, and the potential temporal occurrence of overloading. There are often underlying trends and patterns in traffic such that conditions change on a somewhat routine and predictable basis. These trends may be revealed by characterizing the temporal distribution of the commercial traffic. An obvious example is peaks in traffic demand during the morning and evening rush hours on an urban freeway. Although they may not be as obvious, there may be daily, weekly, and seasonal trends in commercial vehicle activity as well.

The truck traffic volume throughout the study week is illustrated in Figure 4. The lowest truck volumes (345) were observed to occur on Saturday. The weekday volume was fairly uniform and significantly higher than the weekend volume. The highest traffic volume occurred on Monday (905), followed by Thursday (853) and Tuesday (819). Average weekend volume was 424.5 trucks per day, while the average weekday volume was 816.8 trucks per day, almost twice the weekend average.

The hourly traffic volume is illustrated in Figure 5. There is a general trend of low volumes in the morning and evening, with higher traffic volumes through the middle of the day, with truck volumes near 300 per hour through most of the mid-day period.

The rate of overweight occurrences throughout the week are illustrated in Figure 6. Recorded overweights indicate a decreasing trend from the beginning of the week to the end of the week. The highest percentage of overloading occurred on Monday at 18.6 percent and declined each day, with the exception of Friday, with a low of 5.5 percent on Saturday. Although no correlation has been identified, it is interesting to note that Monday was also the day that had the highest truck traffic volume. While there is not as clear a trend throughout the week when the GVW limits are considered, Monday still clearly has the highest rate of vehicles exceeding allowable weight limits at 3.4 percent, more than one percent greater than any other day of the week. The lowest rate of exceeding GVW limits occurs on Sunday at 1.4 percent. Overloading rates of approximately two percent were observed for all other days, varying by no more than +/- 0.3 percent.

The rates of overweight occurrence by time of day are illustrated in Figure 7, broken down into three hour time periods. The late morning and early afternoon period, starting from 6 am and ending at 3 pm, had the highest rate of trucks exceeding one or more limits, with more than 15 percent of trucks overloaded during this time period. During the period of 6 am to 9 pm, rates were all in excess of 11 percent, while the highest rate outside this period was 9.1 percent. Similar results can be seen when the rate of GVW overweight occurrences are examined. Between 6 am and 6 pm, greater than 2.6

percent of all trucks exceeded the allowable GVW. Between 6 pm and 6 am 1.6 percent or less of all trucks exceeded the allowable GVW.

Comparing the daily traffic volumes presented in Figure 5 and the overloading rate in Figure 7, it is noted that the highest rates of trucks exceeding allowable limits (axle and GVW and GVW only) correspond to the time periods of highest truck volume. One possible explanation for this phenomenon may be the increase in localized traffic that occurs during business hours. The closest permanent weigh stations are 25 or more kilometres from Saskatoon and therefore have little enforcement effect on the local traffic. During evening and early morning hours, the truck traffic would be expected to have less local trucks and more long haul trucks, which have been exposed to more permanent enforcement facilities and therefore have greater compliance with regulations.

ROLE OF WIM IN URBAN WEIGHT ENFORCEMENT

A WIM system can play an important role in improving the effectiveness of weight enforcement in an urban environment. Since resources are typically limited for weight enforcement in an urban setting, it is important to use those resources in the most effective way possible. A WIM system can be part of planning and evaluating enforcement strategies and can also be an active part of the enforcement effort with the addition of video capabilities.

Planning and Evaluation of Enforcement Efforts

One approach to improve the effectiveness of enforcement efforts is to strategically select the time and place of enforcement efforts. From the daily and weekly overloading patterns presented earlier, a strategy could be developed as to when enforcement should be done to have the greatest effect. As illustrated in Figures 6 and 7, the times of most frequent overloading were early in the week, particularly Monday, and during the working day.

The WIM data could also be used to target particular classes of vehicles for specific attention. Overall, it was found that 2.2 percent of commercial vehicles exceeded the allowable GVW and 12.8 percent of the commercial vehicles exceeded one or more of the axle, axle group, or GVW weight limits. Figure 8 provides a breakdown of the overweight occurrences in terms of GVW only and axle and/or GVW, for the various classes of vehicles. Class 9 vehicles had the lowest frequency of overweight occurrence, 1.2 percent on GVW limits and 6.7 percent on axle and/or GVW limits. The FHWA 13A and 13B classes had the highest rate of exceeding weight limits, with rates of 6.4 percent and 4.2 percent respectively in excess of GVW limits, and 18.1 percent and 28.6 percent respectively in excess of axle and/or GVW limits. Class 10 and the other grouping with two and three axle trucks had excess GVW weights in 1.8 percent and 2.4 percent of trucks respectively, and excess on axle and/or GVW limits in 13.2 percent and 10.2 percent of trucks respectively.

The WIM system can provide data for measuring the effectiveness of any enforcement efforts that are employed to determine what the reduction in overloading violations was and how long the reductions lasted. This information feeds back into the strategy development to determine what frequency, timing, and level of enforcement is needed. Enforcement efforts are often measured in terms of number of vehicles weighed and number of citations given, but these measures show the effort expended, but do not provide a measure of the desired outcome. More appropriate evaluation methods that consider proportion of overweight trucks, severity of overweight trucks, and excess ESALs have been proposed, all of which are available from the WIM system (6).

Video WIM As An Enforcement Tool

The Video WIM system that is operating on Circle Drive can be used as a tool to improve the effectiveness of weight enforcement efforts. Temporary enforcement set-ups that are commonly used when fixed facilities are not available are limited in the number of vehicles that can be processed, with a thorough inspection taking approximately 45 minutes to conduct. For the vehicle driver and enforcement personnel, the most effective approach is to examine the trucks with the highest likelihood of being in violation (7). Real-time access to video and weight information allows enforcement personnel to increase their effectiveness by selecting only vehicles with a high potential of being in violation. Video images can also be reviewed at a later time, possibly on a weekly or monthly basis, and a trend of repeat offenders may be identified. The result of identifying such a trend could be an “encouragement” letter asking for cooperation from the carrier to rectify the problem, or the pursuit of legal action against the repeat violator for causing damage to the highway infrastructure.

A future step in the use of video enforcement could be an unmanned automated roadside enforcement system that would produce citations based on WIM and vehicle identification technology on a 24/7 basis, similar to photo-radar or red-light cameras. Under current operational and judicial restrictions, this type of system is not currently possible, and advances in technology and changes in laws will be necessary for implementation (8). However, the video WIM system is a step in this direction and may lead to further developments and changes in enforcement practices.

ROLE OF WIM IN TRANSPORTATION PLANNING, DESIGN, AND PRESERVATION

One of the applications of WIM systems has been and continues to be in the planning, design, and preservation of highway infrastructure assets. Accurate monitoring of commercial vehicle weights and dimensions is becoming increasingly necessary for transportation engineers and managers given the trend to an increased amount of larger and more productive vehicle types. In this application, traffic data collected over a period of time is used to provide a clear representation of the loading on the roadway.

For many years empiricism has been used to design pavement structures. With advances in road material science, and the development of new construction approaches, the empirical based approach is not always suitable for predicting the performance of innovative road materials and structures. As well, increasing traffic volumes and commercial vehicle loading are extending beyond conventional traffic predictions used in previous road modeling research. A mechanistic approach to highway structural design, based on understanding the thermomechanical properties of materials, as well as the loads that will be applied, is emerging as a way to more reliably and accurately design and predict the performance of pavement structures. Such examples include traffic load spectra as an input to the AASHTO 2002 mechanistic design procedure. This means that the design is based on the responses of the pavement structure, such as stresses and strains, to specific axle loads. While previous methods summarized input values into a small number of design variables, the mechanistic approach includes detailed characterization of the distribution of loading levels over the vehicle population, known as the axle load spectra. The total number of values describing the axle load spectra of the entire traffic stream approaches 10,000 (9).

Mechanistic design requires a detailed analysis of many variables besides the axle load spectra, but accurate loading information has been determined as the most critical variable to assess accurately (10). Since the proper design will have significant consequences in terms of performance and economics, the use of an accurate WIM system to provide the best estimate of loading is recommended.

The evaluation of pavement performance has long been an important part of highway design, going back to the original AASHTO road tests as mentioned above. With the development of WIM, the ability to conduct research and evaluate performance based on known traffic loading has been enhanced. WIM enhances the capability to measure vehicle loading, and is a key component of evaluation projects such as the Long Term Pavement Performance (LTPP) program, established as part of the Strategic Highway Research Program. LTPP is a 20 year research program, begun in 1989, which includes more than 2000 in-service asphalt and portland cement concrete test sections throughout North America (11). Continued evaluation can provide the data to verify that the science being applied is giving the correct results and expected performance from pavement structures is being realized.

The Relationship Between Overloading and Planning, Design and Preservation

It has been shown that vehicle overloading is occurring on Circle Drive. To begin to assess the impact of overloading due to structural depreciation, the first step is to quantify the excess loading that the structure is being exposed to. While the earlier analysis of exceeding axle and GVW limits indicates the amount of overloading, they do not provide a quantifiable measure that can be related to the performance of the highway structure.

The Guide for Design of Pavement Structures produced by the American Association of State Highway and Transport Officials (12) uses Equivalent Single Axle Loads (ESALs) to quantify the impact of each axle loading relative to the impact caused by an 18,000 pound standard axle. ESALs provided a convenient unit of measure to assess the impact of various types of axle loadings and configurations for typical pavement structures. To assess the impact of overloading at this location, the total ESAL was calculated for each of the commercial vehicles and compared to the maximum allowable ESAL value for that configuration of vehicle, on an axle by axle basis. The total quantity of ESALs and the quantity of ESALs due to overloading was determined for each vehicle type. Results of the ESAL calculations are shown in Table 1, lines 7 to 11.

Overall, it was found that 6.2 percent of the ESALs were due to loading in excess of the allowable limits. The percentage of ESALs due to overloading and percentage of total ESALS is illustrated in Figure 9. When the ESALs from overloading are broken down by Class, it is found that although two and three axle trucks only contribute 10 percent of the total ESALs, 20.6 percent of the ESALs from this class are due to excess loading. This class has the highest percentage of ESALs attributed to overloading and also the highest total ESALs due to overloading. Two and three axle trucks are typically local service vehicles operating in the vicinity of the urban area, and therefore rarely pass by weigh stations located for protection of provincial highways. The lowest percentage of ESALs due to overloading occurred in Class 9 vehicles with only 3.4 percent. The Class 13A and 13B categories had 8.0 percent and 4.9 percent of ESALs created due to overloading respectively, while Class 10 had 6.2 percent of measured ESALs due to overloading.

Based on the results assembled in this analysis, Table 1 and Figure 9 indicate that more attention should be paid to the smaller trucks because although they are less than 20 percent of the population they contribute over 33 percent of the ESALs due to overloading. A common assumption is that big trucks cause damage to the roads and that smaller trucks do not cause much damage. This is true in terms of the total ESALs generated, as 90 percent of the total ESALs come from the Class 9, 10, and 13 trucks. However, with the greater transportation efficiency and the contributions through taxes and other fees, there should be a balance between damage and economic gain when these trucks operate within limits, and therefore this should not be held against the bigger trucks. Despite only contributing 10 percent of the total ESALs and therefore appearing less significant, the group comprised mainly of two and three axle single units is significant because of the quantity of excess ESALs. The focus on big trucks as the cause of damage and the directing of enforcement efforts in this area may be the reason that overloading is so prevalent in the smaller trucks.

The importance of accurately predicting loading and then preventing excess loading is illustrated in Figure 10 which shows the present serviceability index versus traffic loading. The graph in Figure 10 is based on an assumed design loading of five million ESALs, structural number of 2.6, and a subgrade soil resilient modulus of 17,500 psi, initial serviceability of 4.4 and terminal serviceability of 2.0. Assuming the loading predictions were accurate and the structure performs as designed, the serviceability should follow the “design performance” line and provides serviceability greater than 2.5 until the full load is carried.

When excess loading occurs, from either increased traffic or overloaded vehicles, the serviceability will follow the “accelerated loading” line. The first consequence of accelerated loading is lost serviceability in forms of rutting, cracking, roughness, etc.

Observations from the field indicate that rutting and cracking is taking place along the northbound section of Circle Drive. The second consequence of accelerated loading is the hastened deterioration of the pavement structure. Continued overloading will cause the pavement to fall below the minimum serviceability at an earlier date than the 15 year design and will require rehabilitation or reconstruction. Finding the necessary funds earlier than expected to finance large capital projects that have deteriorated faster than expected can be difficult to accommodate in a municipal budget. With a WIM system in place, the loading to date can be measured accurately to estimate the remaining life and identify future funding needs.

SUMMARY

A WIM and video capture system installed in an urban freeway setting was used to determine the extent and patterns of overloading by commercial vehicles. It was found that almost 13 percent of commercial vehicles were in potential violation of the applicable axle, axle group and gross vehicle weight limits, of which more than two percent were in excess of the allowable GVW. Patterns were identified showing the truck types most likely to exceed limits as well as the time of day and days of the week when overloading was most likely to occur.

The analysis showed that the greatest contributor of loading in excess of legal limits were the two and three axle vehicles, which are typically local service vehicles. The analysis also showed that the largest amount of overloading occurred during the workday hours, which is the time when local trucks would be expected to be the most active. Enforcement efforts are often targeted at the larger vehicle types, but the results of this analysis suggest more attention should be paid to two and three axle trucks.

The overloading that is taking place has a negative effect due to the increased structural depreciation of the city’s road asset. More than six percent of the ESALs being applied to this roadway were due to excess loading. The reduction or elimination of the excess loading that is taking place would have a beneficial impact on the service life of the highway section studied and result in savings to the City of Saskatoon and better serviceability to the road user.

The WIM and video capture system used to gather the data needed to understand the problem of overloading can also act as part of the solution. Several applications of this equipment to more effective enforcement activities were identified including developing a strategy of when, where and who to enforce, screening and identification of most likely violators in real time, identification of repeat offenders, and evaluation of the effectiveness of enforcement efforts.

Further research is recommended in the following areas to provide better understanding of commercial vehicle loading in an urban environment:

- The relationship between excess loading on urban freeways and the economic damage caused at both the freeway level and the local street level.

- The relationship between enforcement strategy, enforcement effort, and enforcement effectiveness in an urban setting.
- The optimal routing and balancing of commercial vehicle traffic on an urban freeway network to maximize road asset value and transportation efficiency.

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TABLES

Table 1: ESALs due to overloading by various truck types

	VEHICLE CLASS					
	Other	**FHWA 9**	**FHWA 10**	**FHWA 13A**	**FHWA 13B**	**Total**
1. # of Trucks	1021	2114	779	94	925	4933
2. % OF Total Trucks	20.7%	42.9%	15.8%	1.9%	18.8%	100%
3. # Overweight (Axle and/or GVW Limits)	104	141	103	17	265	630
4. % Overweight (Axle and/or GVW Limits)	10.2%	6.7%	13.2%	18.1%	28.6%	12.8%
5. # Overweight (GVW Limit)	25	26	14	6	39	110
6. % Overweight (GVW Limit)	2.4%	1.2%	1.8%	6.4%	4.2%	2.2%
7. Total ESALs for class	619.1	2105.8	895.4	183.9	2465.9	6270.2
8. ESALs due to overloading	127.5	72.0	55.9	14.7	120.8	390.9
9. % ESALs due to overloading within class	20.6%	3.4%	6.2%	8.0%	4.9%	6.2%
10. % of total ESALs from class	10%	34%	14%	3%	39%	100%
% of total ESALs due to overloading from class	33%	18%	14%	4%	31%	100%

FIGURES

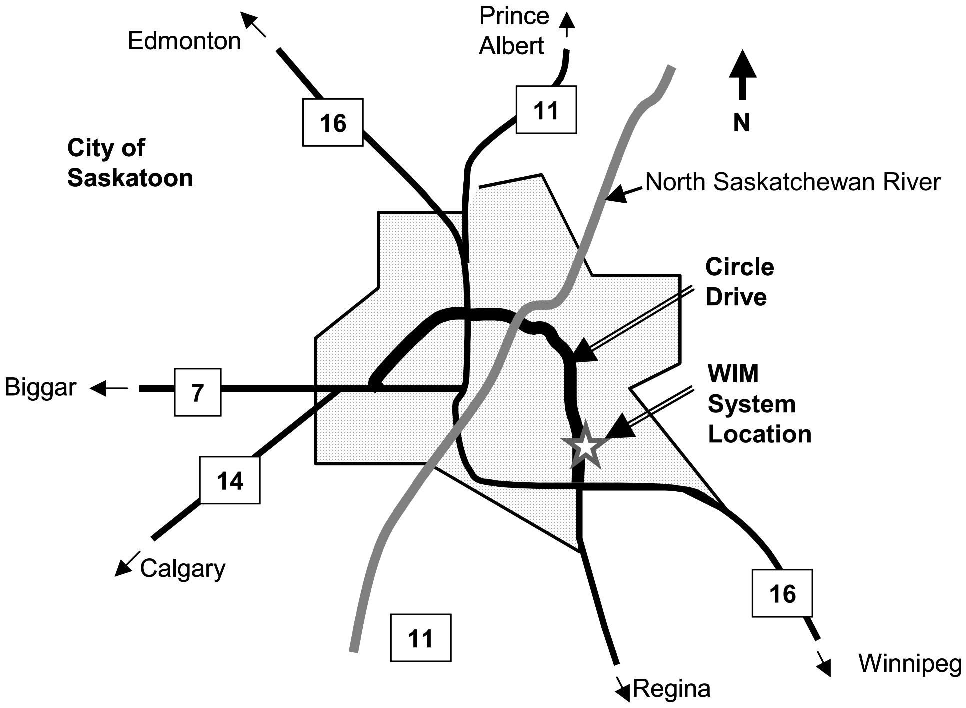

Figure 1 – Location of City of Saskatoon Weigh In Motion System and Major Truck Routes

Figure 2: Weigh In Motion and Video Monitoring Components

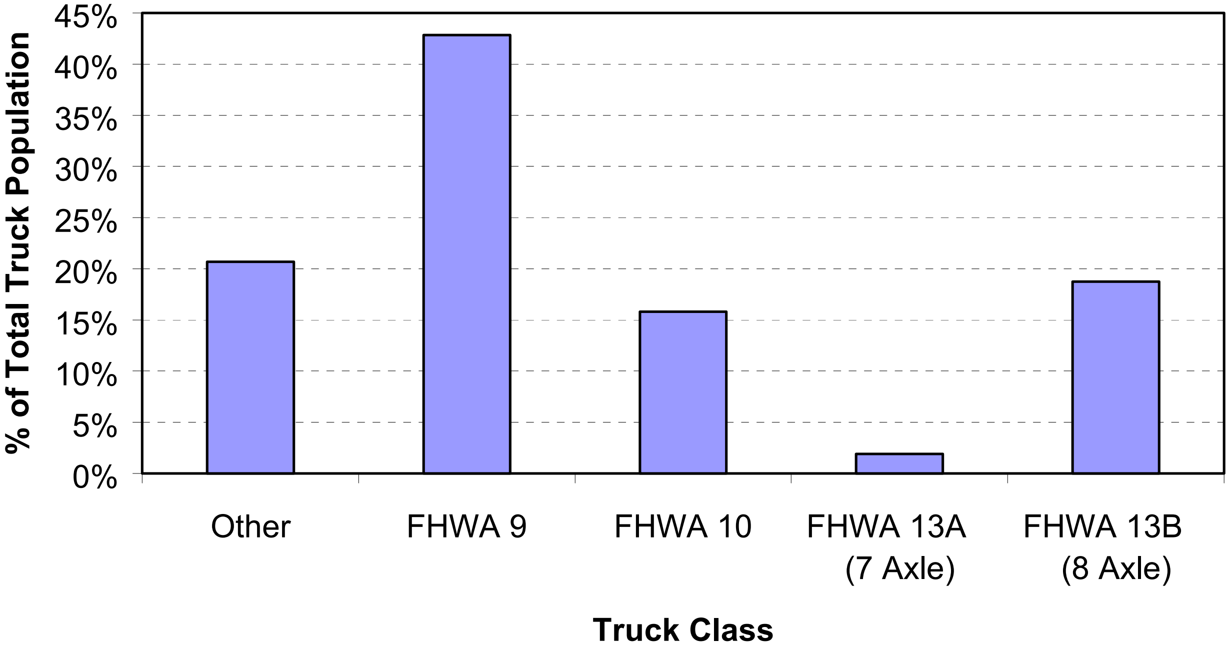

Figure 3: Truck Class Distribution: Percentage of Each Class.

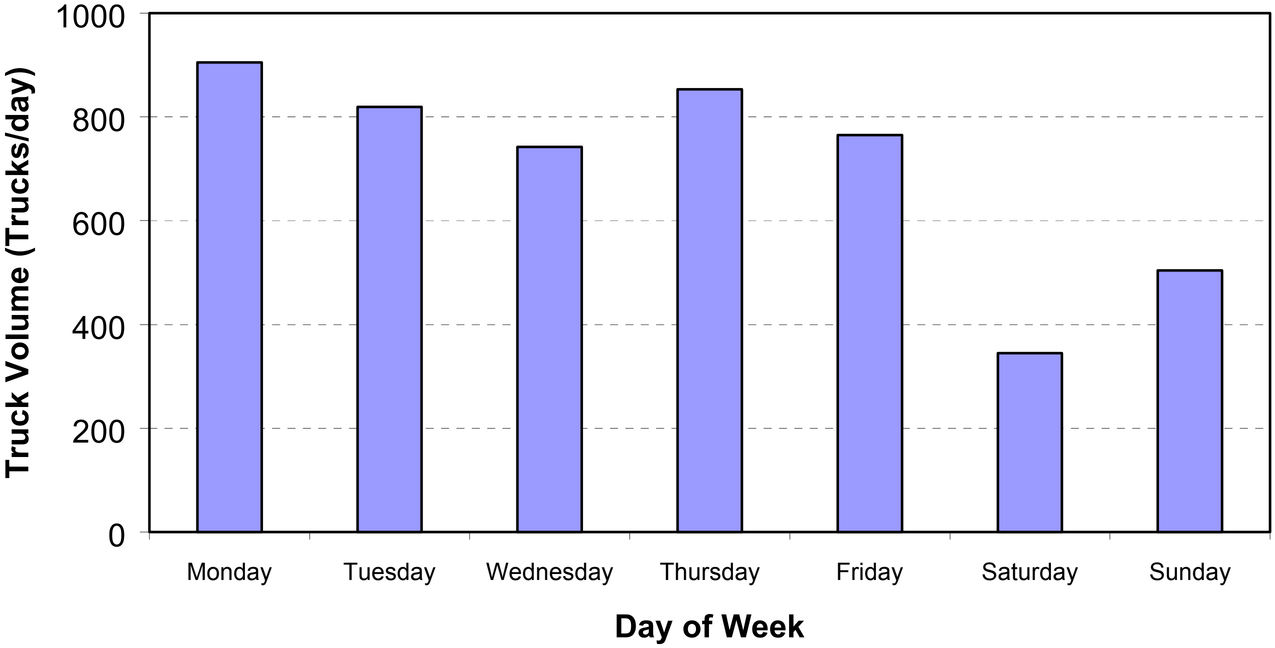

Figure 4: Truck Volumes by Day of Week

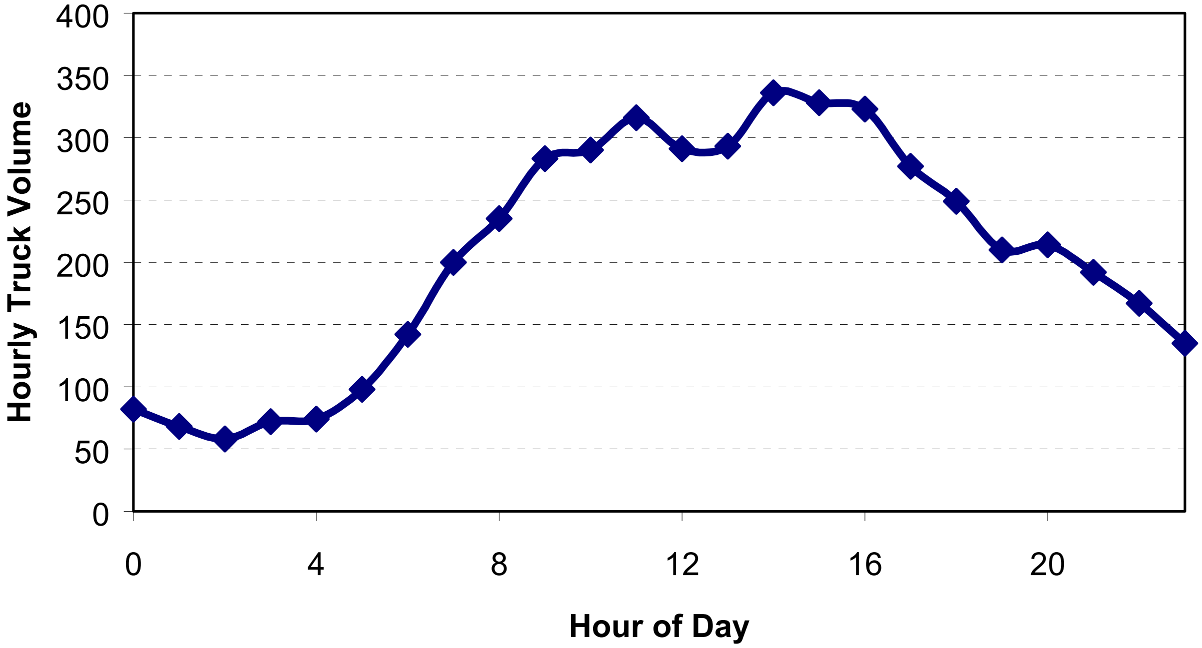

Figure 5: Truck Volume by Time of Day

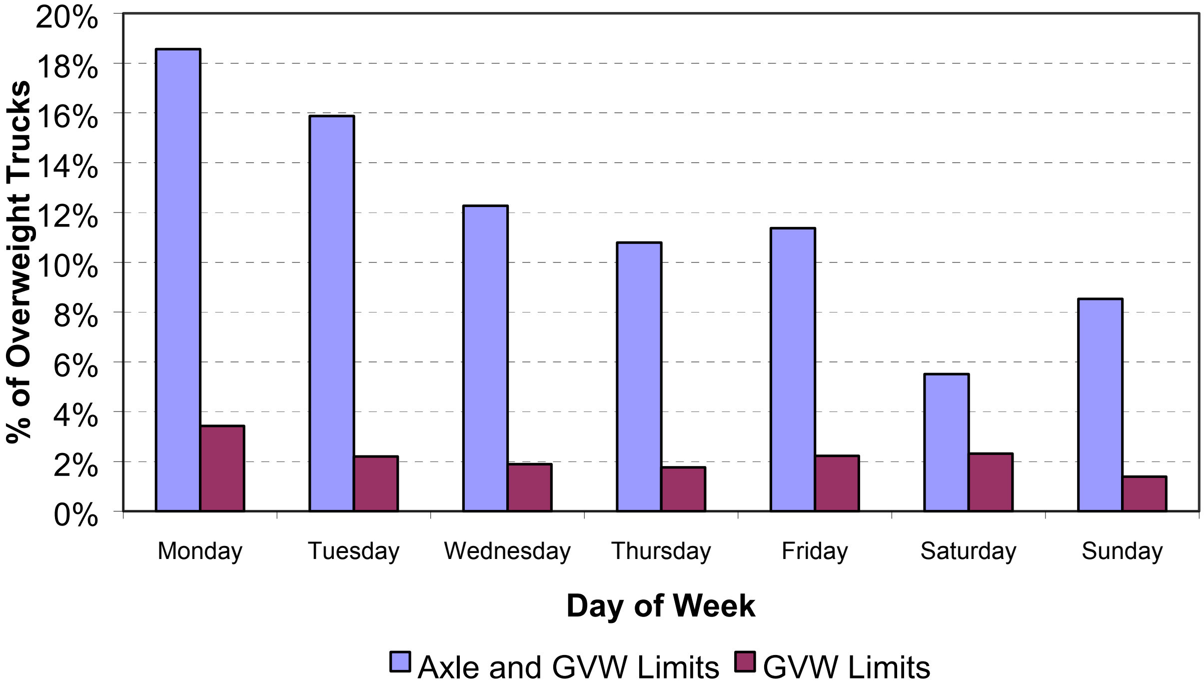

Figure 6: Percentage of Vehicles Exceeding GVW and All Limits By Day of Week

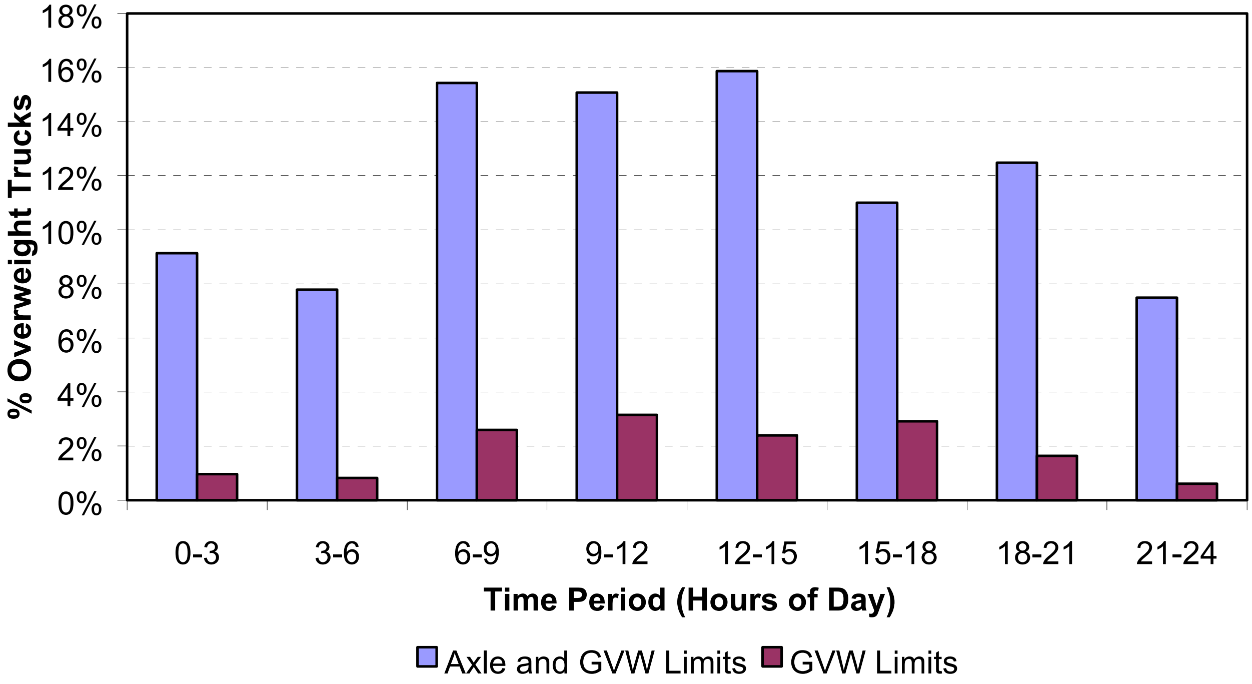

Figure 7: Percentage of Vehicles Exceeding GVW and All Limits by Time of Day

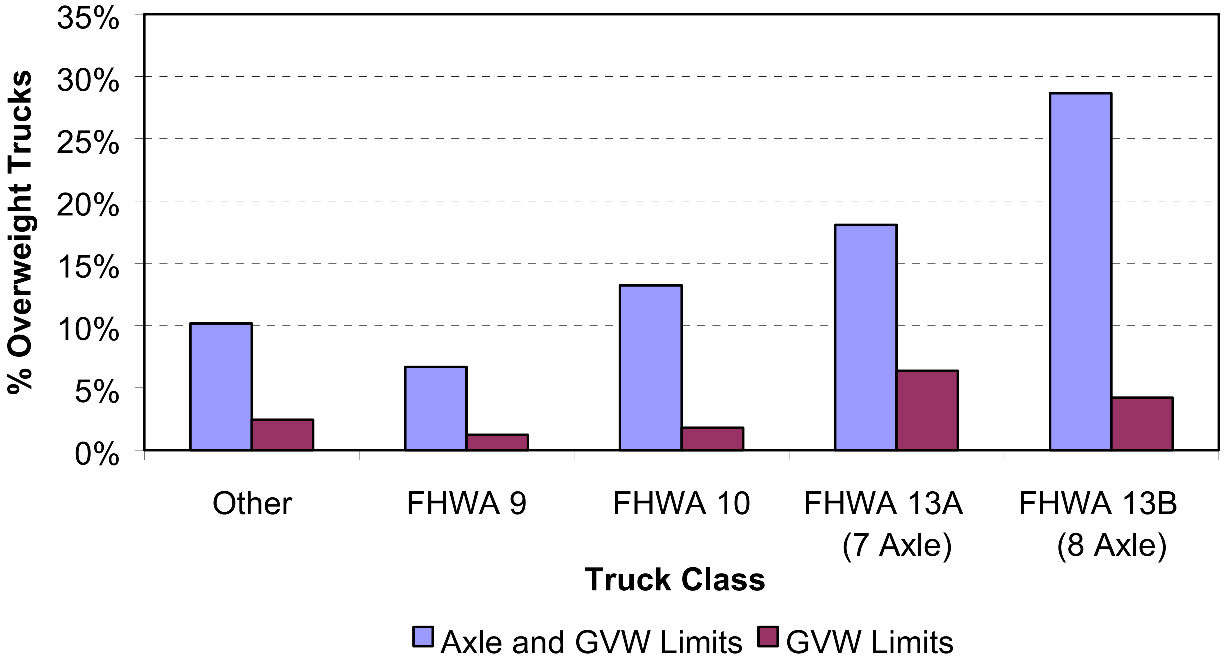

Figure 8: Trucks Exceeding GVW and Axle Weight Limits: Percentage by Class.

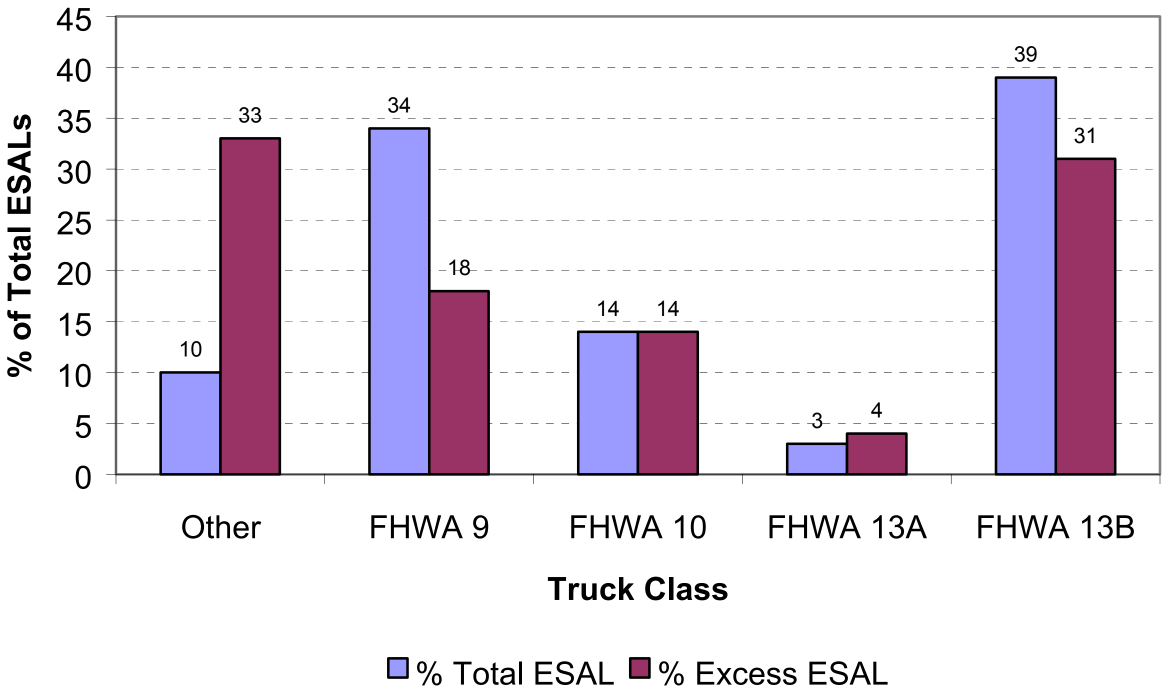

Figure 9: Percentage of total ESALs and Excess ESALs for each truck class

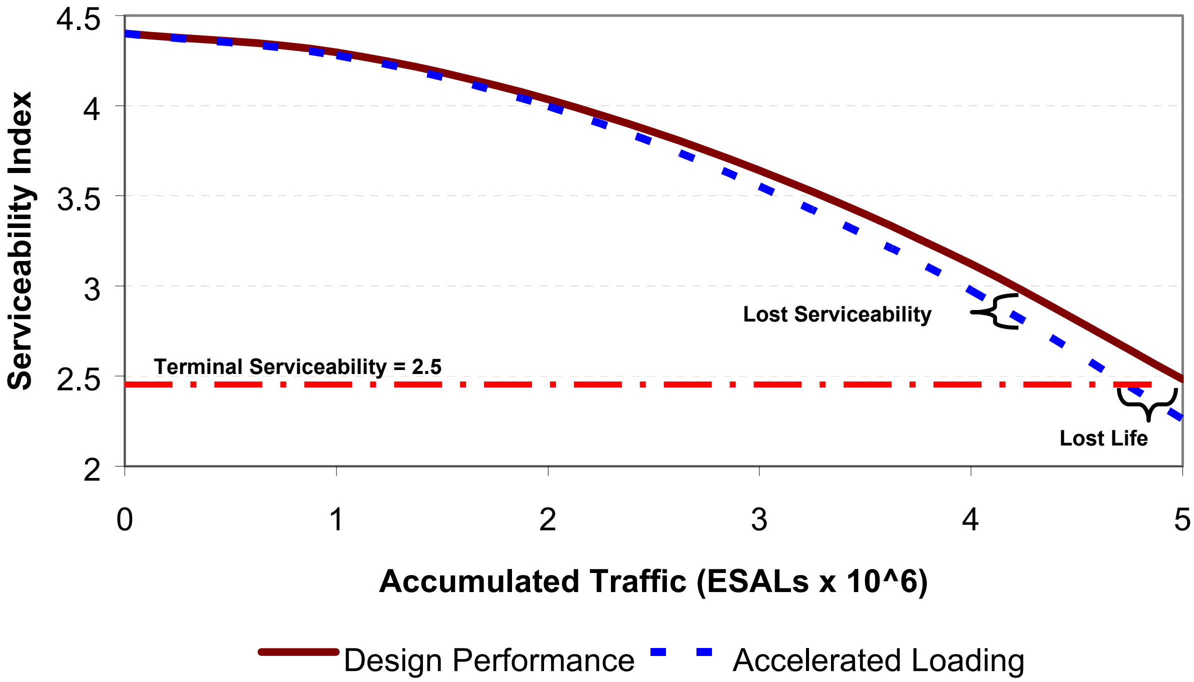

Figure 10: Loss of Serviceability and Life Due To Accelerated Loading