Evaluation of Impacts of Allowing Heavier Log Loads in Northern Wisconsin During Spring Thaw

Samuel Owusu-Ababio, Ph.D., P.E.
Robert Schmitt, Ph.D., P.E.

University of Wisconsin - Platteville
Department of Civil and Environmental Engineering

WisDOT ID no. 0092-11-16
March 2014

RESEARCH & LIBRARY UNIT

WISCONSIN DOT
PUTTING RESEARCH TO WORK

Technical Report Documentation Page

1. Report No.	2. Government Accession No	3. Recipient's Catalog No
4. Title and Subtitle Evaluation of Impacts of Allowing Heavier Log Loads in Northern Wisconsin During Spring Thaw		5. Report Date March 2014 6. Performing Organization Code
7. Authors Sam Owusu-Ababio and Robert Schmitt		8. Performing Organization Report No.
9. Performing Organization Name and Address University of Wisconsin – Platteville Department of Civil and Environmental Engineering 141 Ottensman Hall 1 University Plaza, Platteville, WI 53818		10. Work Unit No. (TRAIS) 11. Contract or Grant No. WisDOT SPR# 0092-11-16
12. Sponsoring Agency Name and Address Wisconsin Department of Transportation Division of Business Management Research & Library Unit 4802 Sheboygan Ave. Rm 104 Madison, WI 53707		13. Type of Report and Period Covered Final Report, 2011-2013 14. Sponsoring Agency Code
15. Supplementary Note		

16. Abstract

This study investigated the impact of a January 1, 2011 Wisconsin statutory change (RS permit law) that allows vehicle combinations up to 98,000 pounds on six axles to transport loads of raw forest products during the spring-thaw suspension period. Prior to the statutory change, Wisconsin DOT could suspend overweight permits for the transportation of raw forest products during the spring thaw, or impose special weight limits on highways. The specific goals of the investigation were to: (1) determine if there is an impact with this statutory change; (2) identify whether certain vehicle classes or categories are more damaging than others, and the possibility of lessening the impact of these heavy loads; and (3) determine if certain pavements are impacted with increased loads due to the policy change.

A total of eleven pavement segments were analyzed in the study and fell into two paved surface categories: older Marshall mix design (4 segments) and newer Superpave mix design (7 segments). The analyses showed that the Superpave mix design segments generally produced better performance than the Marshall mix design segments. Higher levels of alligator cracking and rutting were associated with the Marshall mix segments compared to the Superpave segments. Levels of longitudinal cracking were however, not significantly different between the two mix types. A segment by segment analysis revealed that one Marshall mix segment (age 13 years) exhibited significantly higher rates of progression in alligator and longitudinal cracking in the loaded lane when compared to the adjoining empty lane. Hence, the rehabilitation or replacement of older Marshall segments within the logging route network is needed to allow up to 98,000lbs of raw forest products to be transported on six-axle vehicles, while inflicting lesser damage to the pavement network. In addition, this study was initiated just one year after the implementation of the RS Permit law and focused on only a few segments. A longer time frame and many more segments may be needed to help evaluate the overall long-term impacts from log loaded trucks, or a field test consisting of a special test section could be constructed and subject to the RS permit law trucks to capture their overall impact during the spring-thaw season.

FHWA vehicle classes 9 and 10 were the main carriers of logs throughout the studied network. The relative-log carrying efficiency (with reference to the pavement damage caused) of class 10 trucks averaged approximately 22,000 lbs/ESAL compared to 15,400 lbs/ESAL for class 9 trucks.

A considerable proportion of trucks were found overloaded at two platform scales, averaging 31% and 24% in the winter, and 25% and 33% during the spring. The magnitude of the truck overload, however, averaged less than 5% of the 98,000-lb limit permitted under the law for gross vehicle weight.

17. Key Words Forest products, logging trucks, seasonal load restrictions, frozen ground, thaw, axle loads, overweight limits, pavement performance, Wisconsin Department of Transportation		18. Distribution Statement No restriction. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield, VA 22161	
18. Security Classif.(of this report) Unclassified	19. Security Classif. (of this page) Unclassified	20. No. of Pages 153	21. Price -0-

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Disclaimer

This research was funded by the Wisconsin Department of Transportation and the Federal Highway Administration under Project 0092-11-16. The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Wisconsin Department of Transportation or the Federal Highway Administration at the time of publication.

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof. This report does not constitute a standard, specification or regulation.

The United States Government does not endorse products or manufacturers. Trade and manufacturers' names appear in this report only because they are considered essential to the object of the document.

Executive Summary

This study investigated the impact of a January 1, 2011 Wisconsin statutory change that allows vehicle combinations up to 98,000 pounds on 6 axles to transport loads of raw forest products during the spring-thaw suspension period. Prior to the statutory change, Wisconsin Department of Transportation (DOT) could suspend overweight permits for the transportation of raw forest products during the spring thaw, or impose special weight limits on highways.

The specific goals of the investigation were to: (1) determine if there is an impact with this statutory change; (2) identify whether certain vehicle classes or categories are more damaging than others, and the possibility of lessening the impact of these heavy loads; (3) determine if certain pavements are impacted with increased loads due to policy change; (4) provide a means to identify key destinations/sources of raw forest products; and (5) present tools to help the Wisconsin DOT better forecast these impacts.

The goals of the research study were examined through a series of tasks including: a) review and synthesis of literature on spring load restriction practices, with particular attention to the timing for restrictions and methods used, impact on performance, load restriction benefits, and practices in Wisconsin; b) review of logging industry truck hauling practices in Wisconsin through a survey and direct interviews with members of the Great Lakes Timber Professional Association (GLTPA), Wisconsin DNR managers of forested lands, and commercial land owners of forested property; and c) statistical analyses of traffic and distress data collected for a network of logging truck routes in northern Wisconsin from December 2011 to May 2012. On the basis of the study, the following summary and conclusions are provided.

Literature Review

The literature suggested that seasonal load restriction (SLR) practices are designed to control truck loading before and during spring thaw and inhibit premature damage and higher maintenance costs, as well as reduce economic activity. The following observations are made from the literature:

- In the U.S. and Canada, there has been a shift towards the use of a Cumulative Thawing Index approach and some deflection measurements to determine the start and end dates for SLR. A majority of states in freeze-thaw regions apply restrictions, where 24% use a quantitative method and 24% use a fixed-date method to impose restrictions. A majority of agencies use inspection and observation to remove restrictions with 29% imposing restrictions by date, and 14% use some type of quantitative method.
- Wisconsin DOT manages three distinct weight restriction programs applicable to the state highway system only and do not involve local county or township roads. The programs include: (1) Frozen Road Declaration, (2) Class II roadway restrictions, and (3) springtime posted roads. The frozen road declaration dictates the winter weight limits on frozen roads. The average date for the beginning of the frozen road period in Wisconsin based on 27 years (1984-2011) of data occurs on December 22nd while the 27-year average date for ending the frozen road period is March 4th. The Class II Road program involves all state highways that are judged to have an unstable condition of the roadway subgrade during the period when frost is leaving the ground

such that the travel of vehicles with overweight permits would cause undue damage to the highway. Wisconsin has determined that the 45-year average for imposing spring load restrictions begins on March 9th, while the 45-year average for ending the load restriction occurs on May 9th. The posted road program is applicable to roadway sections that are considered too weak to even withstand the legal load limit of 80,000 pounds during the springtime freezing and thawing period. The posted road program goes into effect during the second week in March until late April or early May.

- Regarding the effect of weight restrictions on pavement life, a 2002 study in Minnesota reported that pavement life can be shortened by 4 to 8% if weight restriction is set a week too late, and reduced further to 5-12% if higher winter axle load premiums are removed a week too late. A 2000 study in Minnesota also estimated that a typical low-volume asphalt road life will be increased by about 10% when the procedure for placing and removing SLR used actual and forecasted average daily temperature. A 1990 Federal Highway Administration report concluded that reducing truck weights by 20% between late February and early May can increase the life of vulnerable pavements by 62%. In addition, a 50% reduction in the truck weight can result in a 95% increase in pavement life. A 2008 study in Alabama, outside the wet-freeze region of this study, demonstrated that changing rear 34,000-lb tandem axles to 51,000-lb tridem axles had no effect on pavement performance when the total weight of the traffic stream was held constant.
- Although SLR has been implemented for many years, very few studies have been conducted to examine the benefits and costs associated with SLR. A 2007 Minnesota study through a survey of industry costs, combined with pavement performance and freight demand models, concluded that the economic benefits without SLR to industry and haulers significantly outweighed the costs of marginally higher damage to local roads. A 2006 North Dakota economic analysis of increasing load limits concluded that the costs associated with eliminating seasonal limits far outweighed the benefits.
- A 2009 Wisconsin study, without directly considering seasonal load practices, concluded that the 98,000-lb 6-axle semi-trailer generates the greatest savings in transport costs for the system user (private companies and individuals who use the Wisconsin highway system). The analysis also showed that savings would accrue to the public agencies in categories for pavement costs, safety, and congestion. Public agencies would not experience savings for structures, where the heavier truck configurations would require additional investment to replace, reinforce, or post some bridges.

Industry Data Collection

Data collected from sectors of the logging industry through surveys and direct interviews addressed several elements to broaden knowledge of logging practices, with the goal of assisting Wisconsin DOT to identify key destinations and sources of raw forest products. Sources of the interviews included the Great Lakes Timber Professional Association (GLTPA), Wisconsin DNR managers of forested lands, and commercial land owners of forested property. The elements of the surveys included: General impact of SLR on logging operations (operating times, key sources and destination of raw forest products, routes, costs, firm size relationship with daily logging trips), and the short-term impacts of the new RS permit law. The interviews and survey revealed the following:

Great Lakes Timber Professional Association(GLTPA)

- Nearly all GLTPA respondents (18 of 19, 95%) indicated changing routes during the SLR period and reducing load to comply with regulations. The combination of longer routes and vehicle changes prevent some 75% of haulers from hauling during the SLR period.
- A comparison between 2010 and 2011 showed average logging trips generated per day increased from 12.8 to 13.0 trips/day. Average miles traveled during the SLR restriction period also increased between 2010 and 2011 from 23,127 miles to 28,354 miles. Average operating cost also increased from $1.75/mile to $1.83/mile, with no explicit reason given, but could have been due to a combination of factors such as variation in log demand destinations being farther in 2011, combined with high fuel prices at the time, or longer detour routes stemming from an initial over-reaction of more local governments posting their roads to avoid a perceived damage anticipated from Wisconsin Statute s.348.27(9m)4, which allows heavier than normal loads to travel on road networks that are not posted.
- Pricing at certain mills are a combined $/cord and $/mile, or $/ton.
- Logging season generally begins after the first frost in October, when sap begins to run, and ends in March when it becomes difficult to drive in thawing soil. Monday through Friday hauling is common, while a few mills operate 24/7. Saturday operations are generally mulch or chips from logging during the weekdays.
- Load limits vary among counties and roadways presenting a challenge for routing logging trucks. Border hauling from Wisconsin to Michigan (or back) presents a permit challenge, where hauling from Wisconsin to Michigan requires one plate, and hauling from Michigan to Wisconsin requires two plates. Michigan log haulers generally do not want to travel into Wisconsin with additional restrictions.
- Seasonal variations affect where the wood is harvested in Wisconsin. Areas with heavier soils allow for more flexibility in the haul routes as the logging companies will have a greater selection of routes to choose from during spring thaw. Tree species is an important factor in the determination of destinations and sources for the raw forest products. With 23 commercial types of trees in Wisconsin forests, the logging companies are drawn to the wood necessary for their products. Based on productivity guidelines (Managed Forest Lands regulations), the rotation age for most hardwoods (including Red Pine) is at least 60 years.

Paper Mill Companies

Destinations of haul trucks were obtained through meetings with four large paper mill companies in the state. The meetings revealed the following:

- The primary destination of loaded log trucks are pulp, paper, and saw mills within the state and along the Michigan and Minnesota borders.
- There are a total of 56 pulp or paper mills, and over 300 sawmills in the state. Other destinations include landings and railroad loadout facilities. Some rail shipments are sent to Canada, Tennessee, or Virginia.
- Numerous mills are located in regions with high-end pavement designs, in particular Portland cement concrete (PCC) pavements. These locations are primarily in the Chippewa and Fox River Valleys.
- Railroad sidings and landings are important generators of logging truck trips. NewPage Corporation operates several large landings in northern Wisconsin, while Domtar Industries and

Thilmany Papers favor railroad sidings to transport logs to mills in the Wisconsin River Valley and Fox River Valley, respectively.

Management of Forested Land

The Forestry Division of the Wisconsin DNR provided the most available recent data (2008) at the time of the study regarding public lands designated for logging, as well as the harvest volumes and directional distribution of logs in Wisconsin. Analysis of the data indicated the following:

- 250 million cubic feet of roundwood was harvested in Wisconsin in 2008.
- Six counties accounted for 73% of the in-take of the roundwood. Wood County received approximately 35% of the total roundwood harvested in Wisconsin (some via rail) while the remaining counties were Lincoln, Marathon, Price, Sawyer, and Outagamie Counties.

Highway Selection and Field Data collection

A comprehensive database was created for all pavement segments in the state under Wisconsin DOT management for the purpose of selecting appropriate segments for field data evaluation. The selection was based on a wide range of factors including: Highways operating 98,000-lb log loads during the spring thaw season, known destination of the loaded log trucks, known direction of loaded and empty log trucks on a given highway, two-lane highways to channel truck traffic to a single directional lane, cooperation by weigh scale operators to collect data, asphalt pavements (not concrete), emphasis on northern logging regions of the state, multiple destinations in a concentrated area to increase data collection productivity, and proximity of the sections to forests damaged by a July 1, 2011 severe thunderstorm in northwest Wisconsin. The process resulted in two logging truck route clusters. One cluster of the routes located in Sawyer and Rusk counties included STH 40, STH 48, STH 27, and STH 27/70. The other cluster involved STH 77 in Burnett and Washburn Counties.

Field data collection involving traffic counts, log truck weight data, and pavement condition measurements were performed at the two logging truck route clusters on a monthly basis between December 2011 and May 2012. WisDOT performed IRI and rut measurements of the chosen destination segments before the Frozen Road declaration in October 2011 and after the spring thaw suspension period in May 2012.

A primary objective of obtaining traffic counts was to estimate the volume by truck classification of loaded and empty logging trucks in order to determine truck class impact on pavement deterioration. The traffic counts were performed using Trax Flex HS™ automatic traffic data recorders to capture bi-directional vehicle classification data on the highway segments. There was near certainty that snowplowing operations would temporarily force removal of the traffic counter tubes from the pavement; therefore, two radar recorders were mounted at two control count stations to ensure continuous traffic measurement. To distinguish between logging trucks (loaded or empty) and all other trucks, visual sampling counts were performed daily at each control station in the morning and afternoon and for specific days at coverage stations. The visual data was used in conjunction with volume data from the automatic traffic recorders to estimate the logging truck volume for each segment.

Log truck weight data were collected from platform scales at the entry to log destinations in the vicinity of the 11 highway segments evaluated in this study. Individual axle weight and axle spacing data were collected monthly before and after the spring thaw suspension period at two weigh scales in the study region. The purpose was to determine the actual axle load and gross vehicle weight distributions for various truck axle configurations to examine their potential effect on pavement performance. In addition to the data obtained by the research team, operators of two scales in the vicinity of the study area provided monthly weight reports for log trucks that entered and exited the wood yard.

Monthly manual pavement performance data collected included longitudinal cracking, alligator cracking, and rutting. Wisconsin DOT also performed IRI and rut measurements of the chosen highway segments in October 2011 (before the Frozen Road Declaration) and in May 2012 (after the Spring Thaw Suspension Period).

On the basis of the analyses of the traffic, log truck weight, and performance data, several observations and conclusions are drawn in the following areas:

Traffic Counts

- FHWA vehicle classes 9 and 10 were the main carriers of logs throughout the studied network. The observed class 10 consists of two truck configurations each with 6 axles except that one has a single 3-axle trailer and the other a single 2-axle "pup" trailer. The Class 9 is an "18 wheel" semi-truck with variable trailer axle spacing.
- There is a general increase in loaded logging truck traffic during the winter months with peaking occurring mostly in December or February along the studied network. There is a significant decline of loaded logging trucks in March, which seems to support logging truckers' assertion from the survey that they either quit running or change routes to comply with spring load restrictions.
- For the majority of the network, loaded logging truck movements peaked in one direction, while empty logging truck movements peaked in the opposite direction.
- The Northbound direction of STH 27 (between STH 70 Stone Lake and Hayward) carried more trucks loaded with logs in the winter (December-February) than in spring (March-May) with the peak load occurring in February at 63 trucks/day and dropping to 4 trucks/day in March. The number of loaded logging trucks in February in the NB direction was approximately eight times that in the SB direction. The total empty logging truck volume in the SB direction was about double that in the NB direction. Logs were predominantly carried by FHWA truck classes 9 and 10. The two vehicle classes formed nearly 100% (61/63) of all the logging truck volume per day in the NB direction during the peak month. In the SB direction, the peak period occurred in January and the two vehicle classes again represented nearly 100% (13/14) of all logging truck trips per day.
- Along STH 77 west of Minong between CTH H and USH 53, loaded truck movements occurred only in the EB direction from January to May, while empty truck movements occurred only in the WB direction for the same period. In other words, there were no WB loaded trucks and no EB empty trucks on this pavement segment. Peak loading occurred in February and April at a rate of

32 trucks/day but dropped to zero in March. The peak for empty logging trucks occurred in February with the minimum occurring in March. FHWA classes 9 and 10 were the main carriers of logs. Class 9 had more logging trips during the peak month of February compared to class 10.

- For the segment of STH 77 east of Minong between USH 53 and CTH M, peak trips for loaded trucks occurred in January for both directions but with higher volume of 51 trucks/day in the EB direction compared to 28 trucks/day for the WB. Loading trip activity stopped in March for the WB direction but continued throughout the entire study period for the EB, which registered a minimum of 19 trucks/day. FHWA vehicle classes 9 and 10 were the main carriers of logs predominantly in the EB direction. Vehicle class 10 however, had more log loaded trips per day throughout the study period.
- For the portion of STH 27/70 (Radisson to Ojibwa), there were twice as many loaded trucks in the EB direction as in the WB direction during the study period. However, during the same period there were more empty trucks in the WB direction than in the EB direction. The EB loading trips peaked in December at a rate of 54 trucks/day and dropped to one truck/day in March, with FHWA classes 9 and 10 carrying 87% of the volume in December. The WB loaded truck volume peaked in February at a rate of 32 trucks/day and dropped to 4 trucks/day in March.
- Along STH 27 (between Ojibwa and Ladysmith), loaded logging truck movement was predominantly SB with a peak average of 23 loaded trucks/day in December and February, then dwindling to 3 trucks per day in March. February was the only month that loading activity occurred in the NB direction with six loaded trucks per day. Classes 9 and 10 carried nearly 100% of the daily loaded truck volume in the SB direction during the study period.
- For the segment of STH 48 between West County line and Exeland STH 40/CTH D, loaded logging truck activity occurred in the EB direction for December only, averaging 21 trucks per day. No loaded logging truck activity occurred in the WB direction during the entire study period. Empty logging trucks were observed in both directions for December with the higher volume (9 trucks per day) occuring in the WB direction. Classes 8, 9, 10, and 12 were carriers of logs in the EB direction in December. Class 9 carried the largest share at nine trucks/day followed by class 12 with six daily trucks. Empty logging truck traffic was dominated by class 9 in both directions.
- For the STH 40 portion between Becky Creek and North County Line, a combined loaded truck volume of 13 trucks/day was observed in the SB direction for December only; no loaded truck movements occurred in the SB direction during the rest of the study period. Of the combined 13 trucks/day, truck class 9 carried 85% or 11 trucks/day whilst the remainder was carried by truck class 8. There were no empty truck movements in the SB direction during the entire study period, except during February where only class 12 empty trucks were observed at a rate of 3 trucks/day. In the NB direction, loaded truck movements occurred only in February at a rate of 3 trucks/day, and all logs were carried by class 10 trucks. No empty truck movements occurred in the NB direction during the study period.
- Along STH 40 (Exeland STH 48 – Radisson STH 27/70), loaded logging truck movement occurred only in the NB direction during the entire study period with peak loading (six trucks/day) occurring in December. Empty logging truck volumes for the NB varied considerably during the study period. The SB attracted a high empty volume of 26 trucks per day for December and no more for the remainder of the study period. All December loadings were carried by class 9 trucks, while January and March loadings were carried by classes 10 and 6, respectively. March loading was 3 trucks/day.

Log Truck Weight

- Log truck weight data were collected from two platform scales in the vicinity of the 11 highway segments. One platform scale station distinguished between FHWA classes but only retained GVW equal or greater than 90,000 lbs. The measurements taken at the platform scales by the research team, coupled with monthly loading reports received from operators of the two platform scales, suggest violations of GVW and axle spectra load limits. During the winter (Dec-Feb), 17.5% (7/40) of loaded FHWA class 10 trucks exceeded the maximum 98,000 lbs GVW limit by an average of 1,620 lbs, while 14.6% (6/41) exceeded the limit by an average of 1,643 lbs in the spring (Mar-May). The monthly scale reports for the sample of truck weights exceeding 90,000 lbs indicated an average of 31% and 24% GVW violations at the two operators' scales during the winter, and 25% and 33% violations during the spring.
- Although there is considerable proportion of overloaded trucks, the magnitude of the average overload is less than 5% of the maximum 98,000 lb legal limit.
- Per Wisconsin Statute s.348.15(br), the single axle load is limited to 23,000 lbs, while the load on a tandem axle is limited to 38,000 lbs during frozen road conditions for vehicles or combination of vehicles that transport peeled or unpeeled forest products cut crosswise on Class A highways and have axle spacing 8 or less feet. Any other time of the year, the numbers reduce to 21,500 lbs and 37,000 lbs, respectively, for single and tandem axles. The results of the loading analysis indicate that no class 10 single-axle load exceeded legal limits for both frozen and non-frozen road conditions. For tandem axles, approximately 12% (4 of 33 axles) exceeded the 38,000-lb limit for frozen roads by an average of 2,910 lbs during the winter. During the spring, approximately 11% (4 of 36 axles) exceeded the 37,000-lb limit by an average of 565 lbs. Per Wisconsin Statute 348.175(br), the allowable load limit for tridem axles with spacing in the range of 9-10 feet corresponds to a load range of 55,000-55,500 lbs for frozen Class A highways. None of the observed loads violated the tridem axle load limit during the winter months. During any other time of the year, Wisconsin Statute s.348.15(br) indicates that for groups of three or more consecutive axles more than 9 feet apart, an additional 4,000 lbs is usually allowed, depending on the distance between foremost and rearmost axles in a group. The observed tridem axle spacing was 10 feet, which corresponds to a load of 47,500 lbs. Approximately 37% (13/35) of tridem axles were in violation of the regulated weight limit.
- None of the FHWA class 9 trucks measured at the platform scales violated the 23,000-lb legal limit set for single axles for frozen roads during the winter (Dec-Feb). During the same period, however, 22% of tandem axles with spacing in the range of 4-7 feet violated the 38,000-lb limit for tandem axles by an average of 570 lbs.
- During the spring, 1 of 22 axles (4.5%) on class 9 trucks was in violation of the single axle load limit by 3,800 lbs. On the tandem axle side, 8.3% (2 of 24) exceeded the 37,000-lb limit by an average of 4,125 lbs.
- The ESAL factor for class 10 log loaded trucks was estimated to be 2.66 for axle loads averaging 14,085 lbs on single axles, 34,615 lbs on tandem axles, and 46,770 lbs on tridem axles. The ESAL factor for class 9 log loaded trucks was 3.27 for axle loads averaging 15,835 lbs for single axles and 33,290 lbs for tandem axles.

- On the basis of the ESAL factor estimates and average log loads, it was deduced that the relative-log carrying efficiency (with reference to the pavement damage caused) of class 10 trucks averages approximately 22,000 lbs/ESAL compared to 15,400 lbs/ESAL for class 9 trucks.

Pavement Performance

On a monthly basis from December 2011 to May 2012, manual pavement performance measurements were recorded for longitudinal cracking, alligator cracking, and rutting for 11 highway segments in opposing lanes; one opposing lane was designated as the "loaded" lane and the other as the "empty" lane.

Analyses of the pavement conditions regarding the loaded and empty lanes for the segments indicate that:

- None of the seven segments (ranging in age from 1 to 8 years) with Superpave mix design surfaces experienced alligator cracking. Three out of four Marshall mix design surfaced segments ranging in age from 12 to 19 years experienced significant alligator cracking. The same seven Superpave mix design segments exhibited low average rut depths (≤ 6mm) compared to the older Marshall mix design segments which had depths ≤ 16.0 mm.
- Only one segment at age 13 years showed any changes in alligator cracking and longitudinal cracking differences between the loaded and empty lanes. The remaining 10 segments ranging in age from 1 to 10 years did not.
- Another segment at age 2 years showed differences in rutting between loaded and empty lanes; the rest of the segments ranging in age from 1 to 19 years did not.
- Ride (roughness) was only significantly different on 1 of 8 segments at age 1 year; no differences were found for 7 of 8 segments with age ranging from 1 to 12 years.
- Loaded and empty 6-axle logging trucks during Spring Thaw produce similar changes in rut depth.

Recommendations

A systematic approach was employed to examine the impact of a January 1, 2011 Wisconsin statutory change that allows vehicle combinations up to 98,000 pounds using 6 axles to transport loads of raw forest products during the spring-thaw suspension period. The impact was evaluated by comparing spring-thaw distress changes associated with adjoining opposing pavement lanes for eleven highway segments that carry log loads predominantly in one direction (loaded lane) and returning predominantly empty in the opposite direction (empty lane).

Based on the results of the study, the following recommendations are made:

- A major objective of this study was to determine if certain pavements are impacted by increased loads due to the RS permit law. A total of eleven pavement segments were analyzed in the study and fell into two paved surface categories: older Marshall mix design (4 segments) and newer Superpave mix design (7 segments). The analyses showed that the Superpave mix design segments generally produced better performance than the Marshall mix design segments. During both winter and spring, higher mean levels of alligator cracking and rutting were associated with the Marshall mix segments compared to the Superpave segments. Mean levels of longitudinal cracking were however, not significantly different between the two mix types. A segment by segment analysis also revealed that one Marshall mix segment (age 13 years) exhibited significantly higher rates of progression in alligator and longitudinal cracking in the loaded lane when compared to the adjoining empty lane. Hence, the rehabilitation or replacement of older Marshall segments (which are already nearing their terminal lives) within the logging route network is needed to allow up to 98,000lbs of raw forest products to be transported on six-axle vehicles, while inflicting lesser damage to the pavement network. In addition, this study was conducted one year after the implementation of the RS permit law for a small number of segments; a longer time frame and many more segments may be needed to help evaluate the overall long-term impacts from log loaded trucks, or a field test consisting of a special test section could be constructed and subject to the RS permit law trucks to capture their overall impact during the spring-thaw season.

- To identify whether certain vehicle classes are more damaging than others, the ESAL factor estimates in this study suggest that class 9 log loaded trucks with an ESAL factor of 3.27 creates more damage than class 10 loaded trucks with an ESAL factor of 2.66. In addition, the class 9 results in a lower relative-log carrying efficiency of 15,400 lbs/ESAL compared to 22,000 lbs/ESAL for the class 10. It is recommended that Wisconsin DOT coordinate with the logging industry to promote the use of vehicle classes (such as the class 10), which yield higher relative-log carrying efficiencies. Such practices will lessen the damaging effect, especially along portions of the logging route network with older paved surfaces originally designed using the Marshall mix design method.
- With all other factors (besides traffic) controlled such as in this study, deterioration of pavements is a contribution from all vehicle types and not only log-related trucks. The study may be extended to capture the damage contribution by truck categories that carry other heavy commodities during the spring-thaw season across the same routes used by logging trucks. In this way, relative-load carrying efficiencies with reference to the pavement damage caused can be established across the different truck categories based on the amount and type of heavy commodity carried. This input can be part of any comprehensive and efficient approach for the recovery of pavement damage costs from individual heavy commodity trucks (HCTs). In addition, such a study will provide improved information on where and how much HCT-related damage is occurring around the network to determine maintenance activities, improve loading practices such as reduced axle and GVW, as well as encourage the use of a more pavement-friendly fleet of HCTs with characteristics such as an increase in the number of axles per vehicle.
- The study found a considerable proportion of trucks to be overloaded, but the average magnitude of the overload was less than 5% of the 98,000-lb maximum GVW limit permitted under the RS permit law. It is recommended that Wisconsin DOT coordinate with the logging industry to immediately address the problem before overload magnitudes become excessive and create unwarranted damages to the pavements.

Acknowledgments

The authors wish to thank the Wisconsin Department of Transportation for sponsoring this study to advance the understanding of this topic, and to the executive director, members and affiliates of the Great Lakes Timber Professionals Association (GLTPA) for their valuable cooperation during the study. The efficient collection of questionnaire survey data and field data would not have been possible without the support of the GLTPA.

The authors also thank the Wisconsin Department of Natural Resources and to commercial land owners for their input on management practices of forested lands, as well as providing an inventory of logging lands.

A special thanks to the Pavement Data Unit of the Wisconsin Department of Transportation for their assistance with semi-automated pavement performance data collection. The county highway departments of Washburn, Sawyer, and Rusk Counties are thanked for coordination of traffic recorders fastened to the roadway during periodic snowfalls.

The authors also wish to thank the following University of Wisconsin-Platteville research assistants for their valuable contributions to this research: Alex Feuling, Alex Popp, Adam Ryan, Adam Watkins, Brian Genskow, Cayleigh Snodgrass, and Greg Flohr.

List of Tables

Table 2.1 Maximum Winter Weight Limitations (WisDOT 2011d) 5
Table 2.2 Wisconsin Frozen Road Declaration History (WisDOT 2011b; 2011c) 6
Table 2.3 SLR and Removal Dates for Wisconsin and Neighboring States 10
Table 2.4 Benefit-Cost of Heavier Truck Loads (Cambridge 2009) 11
Table 2.5 Cost Savings from SLR of Selected European Countries (Isotalo 1993) 14
Table 2.6 Benefits from Spring Load Restriction (FHWA 1990) 15
Table 2.7 Thaw Weakening Development Factors (Saarenkento and Aho 2006) 15
Table 3.1 Basic Comparative Statistics of RS Permit Law on Logging Operations 21
Table 3.2 Roundwood Volume Demand and Supply for High Intake Counties 25
Table 3.3 Pulp and Paper Mills in Wisconsin (Center for Paper Business 2011) 27
Table 3.4 Pulp and Paper Mills Removed from Field Experimentation 30
Table 3.5 Pulp and Paper Mills receiving 98,000-lb Log Trucks on Asphalt Pavements 31
Table 3.6 Pulp and Paper Mills not receiving 98,000-lb Trucks on Asphalt Pavements 31
Table 3.7 Largest Sawmills in Wisconsin Exceeding 11 Million Board-Feet Annually 32
Table 3.8 NewPage Landings with 98,000-lb Trucks during Spring Thaw 33
Table 3.9 Railroad Sidings with 98,000-lb Trucks during Spring Thaw 33
Table 4.1 Databases Accessed for the Study 38
Table 4.2 Destinations of 98,000-lb Log Trucks during Spring Thaw 42
Table 4.3 Primary Candidate Pavement Segments for Field Evaluation 43
Table 4.4 Other Candidate Pavement Segments for Field Evaluation 44
Table 4.5 Highway Segments chosen for Data Collection 47
Table 5.1 Monthly Traffic and Distress Data Collection 49
Table 5.2 Weekly Count Schedule for Sample Network 51
Table 6.1 Adjustment Table Example for FHWA Class 9 Truck derived from Hayward Control Station 58
Table 6.2 2010 Daily and Seasonal Factors for Factor Group 6 (WisDOT, 2011) 60
Table 6.3 STH 27 Control Station Count for February in the SB Direction 65
Table 6.4 STH 77 Westbound Coverage Data Expanded to 24-hr Volume 66
Table 6.5 Daily volume variation adjustment factor estimate for SB traffic on STH 27 (February 2012) 67
Table 6.6 Daily Volume Variation Factors for STH 27 Control Station 67
Table 6.7 STH 77 Westbound Coverage Data Adjusted by Daily Volume Variation Factor 68
Table 6.8 Daily Volume Variation Factors for STH 27/70 Control Station 76
Table 6.9 Summary of Logging Truck Volume Variation Patterns 89
Table 6.10 Axle Spacing and Weights for FHWA Class 9, 5-Axle Semi Truck 93
Table 6.11 Axle Spacing and Weights for FHWA Class 10, 6-Axle Semi Truck 96
Table 6.12 Axle Spacing and Weights for FHWA Class 10, 6-axle Truck with a"Pup" Trailer 97
Table 6.13 Monthly Logging Reports from Scale #1 100
Table 6.14 Monthly Logging Reports from Scale #2 101
Table 6.15 Average ESAL Factors for Logging Trucks 103
Table 7.1 Simple Linear Regression Models 118
Table 7.2 Statistically determined Pavement Performance Rate Changes for 11 Highway Segments 119
Table 7.3 ANOVA Results for Impact of Mix Type on Performance Measures 120
Table 7.4 Comparison of Linear Relationships of Loaded and Empty Lanes 124
Table 7.5 Statistical Difference of Pavement Performance Rate Changes between Loaded and Empty Logging Truck Lanes 125
Table 7.6 Statistical One-Sample t-test Results for March 2012 Pavement Performance Difference between Loaded and Empty Logging Truck Lanes 128

List of Figures

Figure 2.1 SLR on State, County, or City Roads (Ovik et al. 2000) 2
Figure 2.2 Wisconsin Climatological Zones for SLR Analysis (WisDOT 2011a) 4
Figure 2.3 Class II Roads within Highway Network (WisDOT 2011e) 8
Figure 2.4 Springtime Posted Roads (WisDOT 2011f) 9
Figure 2.5 Benefit/Cost Ratio of Lifting SLR Policy for Three Minnesota Counties (Smalski et al. 2006) 12
Figure 3.1 Wood Products Supply Chain (Stewart et al. 2010) 19
Figure 3.2 Counties Receiving the Bulk of Harvested Roundwood in Wisconsin 24
Figure 3.3 Government Forest Lands in Wisconsin 34
Figure 3.4 Mill Locations in Wisconsin 35
Figure 4.1 Segment Locations for Field Data Collection 45
Figure 5.1 Illustration of Control and Coverage Count 50
Figure 5.2 Hayward traffic counter on STH 27 52
Figure 5.3 Radisson traffic counter on STH 27/70 52
Figure 5.4 Manual Pavement Distress Measurement 53
Figure 5.5 Wisconsin DOT Pavement Distress Measurement on STH 40 54
Figure 5.6 Truck Axle Weight and Spacing Measurement 55
Figure 6.1 STH 27 Control Count Station Location in Hayward, WI 57
Figure 6.2 Directional AADTT Variations at STH 27 Control Station for Combined 60
FHWA Vehicle Classes 6-13 60
Figure 6.3 FHWA Vehicle Class by Class Directional AADTT variations at 61
STH 27 Control Station 61
Figure 6.4 Coverage Count Locations on STH 77 63
Figure 6.5 Directional Volume variations at STH 77 Coverage Station at Minong 69
Figure 6.6 FHWA Vehicle Class by Class Directional Volume Variations at the STH 77 Coverage Station at Minong 69
Figure 6.7 Directional Volume Variations at STH 77 Coverage Station near CNR Bridge 71
Figure 6.8 FHWA Vehicle Class Directional Volume variations at STH 77 Coverage Station at CNR bridge 71
Figure 6.9 Control Count Station Location on STH 27/70 73
Figure 6.10 Directional AADTT Variations at STH 27/70 Control Station for Combined 73
FHWA Vehicle Classes 6-13 73
Figure 6.11 FHWA Vehicle Class Directional Volume Variations at STH 27/70 Control Station at Radisson 74
Figure 6.12 STH 27 Coverage Count Location at the Thornapple River Bridge Crossing 75
Figure 6.13 Directional Combined FHWA Vehicle Classes 6-13 AADTT 77
Variation at STH 27 Coverage Station at the Thornapple River Bridge Crossing 77
Figure 6.14 FHWA Vehicle Class Directional Volume variations at STH 27 Coverage Station at the Thornapple River Bridge Crossing 78
Figure 6.15 Counter Location at STH 48 Coverage Station at Wiergor 80
Figure 6.16 Combined FHWA Classes 6-13 AADTT Variations for STH 48 at Wiergor 80
Figure 6.17 FHWA Vehicle Class Directional Volume Variations for STH 48 Coverage Station at Weirgor 81
Figure 6.18 STH 40 Coverage Station Location at Radisson 83
Figure 6.19 Combined FHWA Classes 6-13 AADTT Variations for STH 40 at Radisson 83
Figure 6.20 FHWA Vehicle Class Directional Volume Variations for STH 40 Coverage Station at Radisson 84
Figure 6.21 STH 40 Coverage Station South of W County Line Rd 86

Figure 6.22 Combined FHWA Classes 6-13 AADTT Variations for STH 40 South of W County Line Rd 86
Figure 6.23 FHWA Vehicle Class Directional Volume Variations for STH 40 South of W. County Line Rd 87
Figure 6.24 Logging Trucks in FHWA Classes 7, 9 and 10 91
Figure 6.25 Measurement of Individual Axle Weight and Spacing on Platform Scale 92
Figure 6.26 Monthly Axle Load Spectra for FHWA Class 9 Sampled Trucks at Platform Scales 95
Figure 6.27 Loaded FHWA Class 10 Monthly Gross Vehicle Weight Distribution at Platform Scales ... 98
Figure 6.28 Monthly Axle Load Spectra for Sampled FHWA class 10 Trucks at Platform Scales 99
Figure 7.1 Highway Segment #1 Performance, STH 77 Burnett County, Age 1 year, Superpave Warranty E-1 106
Figure 7.2 Highway Segment #2 Performance, STH 77 Washburn County, Age 7 years, Superpave E-1 107
Figure 7.3 Highway Segment #3 Performance, STH 77 Washburn County, Age 13 years, Marshall MV-2 108
Figure 7.4 Highway Segment #4 Performance, STH 77 Washburn County, Age 12 years, Marshall MV-2 109
Figure 7.5 Highway Segment #5 Performance, STH 27 Sawyer County, Age 8 years, Superpave Warranty E-1 110
Figure 7.6 Highway Segment #6 Performance, STH 27/70 Sawyer County, Age 2 years, Superpave Warranty E-1 111
Figure 7.7 Highway Segment #7 Performance, STH 27/70 Sawyer County, Age 13 years, Marshall MV-2 112
Figure 7.8 Highway Segment #8 Performance, STH 27 Rusk County, Age 7 years, Superpave E-1 113
Figure 7.9 Highway Segment #9 Performance, STH 48 Sawyer County, Age 1 year, Superpave Warranty E-1 114
Figure 7.10 Highway Segment #10 Performance, STH 40 Rusk County, Age 1 year, Superpave Warranty E-1 115
Figure 7.11 Highway Segment #11 Performance, STH 40 Sawyer County, Age 19 years, Marshall LV-1 116
Figure 7.12 Means and 95% LSD Interval Plots for Mix Design Type on Performance (*Dec-Feb*) 121
Figure 7.13 Means and 95% LSD Interval Plots for Mix Design Type on Performance (*Mar-May*) 122
Figure 7.14 Rutting changes from Daily 6-axle Logging Trucks in March 2012 132
Figure 7.15 Rutting changes from Daily 6-axle Logging Trucks in April 2012 132
Figure 7.16 Rutting changes from Daily 6-axle Logging Trucks in May 2012 133

Table of Contents

Disclaimer i

Executive Summary iii

Literature Review iii

Industry Data Collection iv

Highway Selection and Field Data collection vi

Traffic Counts vii

Log Truck Weight ix

Pavement Performance x

Recommendations x

Acknowledgments xii

List of Tables xiii

List of Figures xiii

Chapter 1 - Introduction 1

1.1 Background 1

1.2 Objectives 1

1.3 Organization of Report 1

Chapter 2 - Seasonal Load Restriction Practices 2

2.1 Introduction 2

2.2 SLR Practices in the U.S. and Canada 2

2.3 SLR Practices in Wisconsin 3

2.3.1 Frozen Road Declaration Program 4

2.3.2 Class II Roads Program 7

2.3.3 Posted Roads 8

2.4 SLR Practices in Neighboring Midwestern States 9

2.5 Economic Impacts of SLR 10

2.6 SLR Impact on Pavement Performance 14

2.7 Limiting Pavement Damage Using Tire Pressure Control Systems 16

2.8 Summary of SLR Practices and Economics 17

Chapter 3 – Logging Industry Truck Hauling Practices 19

3.1 Introduction 19

3.2 Overview of Logging Supply Chain 19

3.3 Great Lakes Timber Professionals Association Survey 20
3.3.1 Impact of Restrictions on Log Hauler Operations 20
3.3.2 Short-term Impact of Wisconsin Statutes 21
3.3.3 Impact of Logging Firm Size on Logging Trip Generation 21
3.4 Logging Congress 22
3.5 Wisconsin Department of Natural Resources 24
3.6 Industry Lands 25
3.7 Mills, Landings, and Railroad Loadouts 26
3.8 GIS Mapping of Logging Operations Influential Factors 33
3.9 Summary 35
Chapter 4 – Field Experimental Design 38
4.1 Introduction 38
4.2 Database of Flexible Pavements 38
4.3 Pavement Selection 39
4.4 Sampling Approach 40
4.5 Candidate Highways 41
4.6 Highway Selection 46
4.7 Summary 48
Chapter 5 – Data Collection 49
5.1 Introduction 49
5.2 Traffic Data 49
5.3 Performance Data 52
5.4 Truck Weight Data 54
5.4.1 Truck Axle Weight and Spacing 54
5.4.2 Monthly Log Truck Reports 55
Chapter 6 – Traffic Data Analysis 56
6.1 Introduction 56
6.2 Traffic Counts 56
6.2.1 STH 27 at Hayward 56
6.2.2 STH 77 in Burnett and Washburn Counties 62
6.2.3 STH 27/70 at Radisson 73
6.2.4 STH 27 at Thornapple River Bridge Crossing 75
6.2.5 STH 48 in Sawyer County 80
6.2.6 STH 40 in Radisson 82

6.2.7 STH 40 in Rusk County 86
6.3 Log Truck Weight 91
6.3.1 Individual Axle Weights and Spacings 92
6.3.2 Monthly Logging Truck Weight Reports 100
6.3.3 Traffic Loading Estimates 101
Chapter 7 – Pavement Condition Data Analysis 104
7.1 Introduction 104
7.2 Pavement Condition Data 104
7.3 Monthly Plots of Performance Measures 105
7.4 Simple Linear Regression Models 117
7.5 Impact of Mix Design Type on Performance 120
7.6 Statistical Comparison of Regression Parameters for Loaded and Empty Lanes 122
7.7 Changes in Pavement Condition during Spring Thaw Months 126
7.8 Changes in Pavement Condition by Vehicle Class 128
7.9 FHWA Class 10 Impact Assessment 131
7.10 Summary 134
Chapter 8 – Conclusions and Recommendations 137
8.1 Summary and Conclusions 137
8.1.1 Literature Review 137
8.1.2 Industry Data Collection 139
8.1.3 Management of Forested Land 140
8.1.4 Highway Selection and Field Data collection 140
8.1.5 Traffic Counts 141
8.1.6 Log Truck Weight 143
8.1.7 Pavement Performance 144
8.2 Recommendations 144
References 147
Appendix 150

Chapter 1 - Introduction

1.1 Background

On January 1, 2011, Wisconsin Statute s.348.27(9m)4 was revised to allow vehicle combinations up to 98,000 lbs using 6 axles to transport loads of raw forest products during the spring-thaw suspension period. Prior to the law change, WisDOT could suspend oversize/overweight permits for the transportation of raw forest products during the spring thaw, or impose special weight limits on highways. At this time, there is no information or data available for the impact of these changes on pavement life or the adverse conditions that may result due to heavier loads during spring thaw.

1.2 Objectives

The objectives of this study are to determine the impacts of allowing up to 98,000-lb 6-axle vehicle combinations on asphalt pavement performance. The study objective is to address the following specific areas:

- Determine effect of revisions on pavement life.
- Identify whether certain vehicle classes/categories are more damaging than others, and possibility of lessening the impact of these heavy loads.
- Determine if certain pavements are impacted with increased loads due to policy change.
- Provide a means to identify key destinations/sources of raw forest products.
- Present tools to help the Department better forecast these impacts.

1.3 Organization of Report

The report is written in eight chapters that are generally divided into two halves, with the first half summarizing activities to prepare for a field evaluation, and the second half summarizing the field evaluation and recommendations. Chapter 2 contains reviews of literature from seasonal load restriction practices in the U.S. and Canada, with special emphasis on Wisconsin and neighboring states. Chapter 3 synthesizes logging industry resource data from multiple sources including a questionnaire survey, as well as notes from meetings with forestry land owners and large pulp and paper mill companies. The resource data are used to create GIS maps to depict origins, haul routes, and destinations of raw forest products. Chapter 4 describes a pavement database that was developed for the selection and evaluation of highway segments in the Northwest area of the state.

Chapter 5 describes field data collection and basic summary statistics from these highway segments. Data collected include traffic counts, pavement distresses, and log truck loading. Chapter 6 analyzes the traffic data pertaining to classification and weight characteristics. Chapter 7 presents detailed statistical analyses on the distress data to determine the effect of heavier log loads on pavement condition. Finally, Chapter 8 summarizes the project including recommendations for Wisconsin DOT and Industry.

Chapter 2 - Seasonal Load Restriction Practices

2.1 Introduction

The primary goal of seasonal load restriction practices is to strike the right balance between minimizing maintenance costs associated with road damage, and minimizing economic loss due to restricting weights for trucks. Selecting the date for seasonal load restriction (SLR) has a significant impact on the life expectancy of a pavement. Inaccurate determination of the start and end dates of load restrictions can result in premature damage and higher maintenance costs or reduced economic activity. The following sections summarize SLR practices in the U.S. and Canada, with special emphasis on Wisconsin and neighboring Midwestern states.

2.2 SLR Practices in the U.S. and Canada

SLR practices in the U.S. and Canada vary in both duration and extent, as well as on technical criteria and agency practices. In the U.S., Ovik et al. (2000) reported that about 22 states experience some variation of freeze-thaw conditions (see Figure 2.1). The timing for SLR was reported to typically begin in late February or early March, and lasts through April or May over a period of at least eight weeks. The methods commonly used include the following:

- Setting the date by the calendar each year;
- Engineering judgment;
- Pavement history;
- Pavement design;
- Visual observations, such as water seeping from the pavement;
- Restricting travel to night-time hours (appropriate for unpaved roads only);
- Frost depth measurement using drive rods, frost tubes, and electrical sensors;
- Daily air and pavement temperature monitoring; and
- Deflection testing.

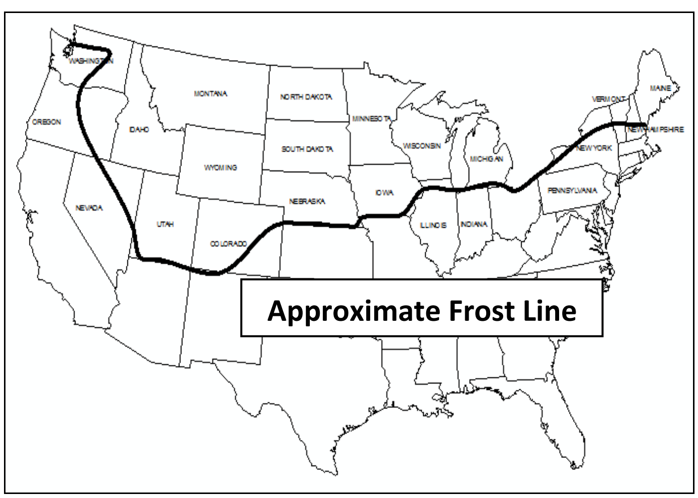


Figure 2.1 SLR on State, County, or City Roads (Ovik et al. 2000)

Kestler et al. (2000) surveyed 45 State Highway Agencies (SHAs) and several U.S. Forest Service (USFS) regional offices regarding the methods used to determine the timing for implementing and removing load restrictions. Out of the 36 SHAs and three USFS regional offices that responded to the survey:

- 52% use inspection and observation.
- 24% of agencies indicated using some kind of a quantitative method.
- 24% use a fixed-date method to impose restrictions.

Regarding removal of restrictions:

- 57% used inspection and observation.
- 29% reported restrictions to be imposed by date.
- 14% reported using a quantitative method.

In Canada, most provinces impose SLR during March and remove the restrictions in May. Deflection testing is used by the majority of provinces, while frost tubes are used primarily in British Columbia and Quebec. Exemptions are granted by most provinces for vehicles that carry dairy products. In addition, utility and emergency vehicles are granted exemptions. Permanent and portable weigh stations are used as the main enforcement tools. The thaw index equation proposed by Leong et al. (2005) is used:

$$\text{Thaw Index} = \Sigma\ (\text{Average Daily Temperature} + 3.4) \tag{2.1}$$

Huen et al. (2006) proposed a similar equation for Northeastern Ontario based on a reference temperature of -5.4 ˚C, resulting in a thaw index expression:

$$\text{Thaw Index} = \Sigma\ (\text{Average Daily Temperature} + 5.4) \tag{2.2}$$

2.3 SLR Practices in Wisconsin

SLR practices for the Wisconsin DOT are designed to protect flexible pavements from premature or accelerated damage during the springtime freezing and thawing period while allowing trucks hauling logs, salt or winter abrasive to increase loads during the winter months when the pavement layers are frozen. Wisconsin DOT manages three distinct weight restriction programs including:

- Frozen road declaration;
- Class II roads; and
- Springtime posted roads.

These programs are applicable to the state highway system only and do not involve local, county or township roads. Wisconsin is divided into five distinct climatological zones for the purpose of SLR. The zone descriptions are shown in Figure 2.2.

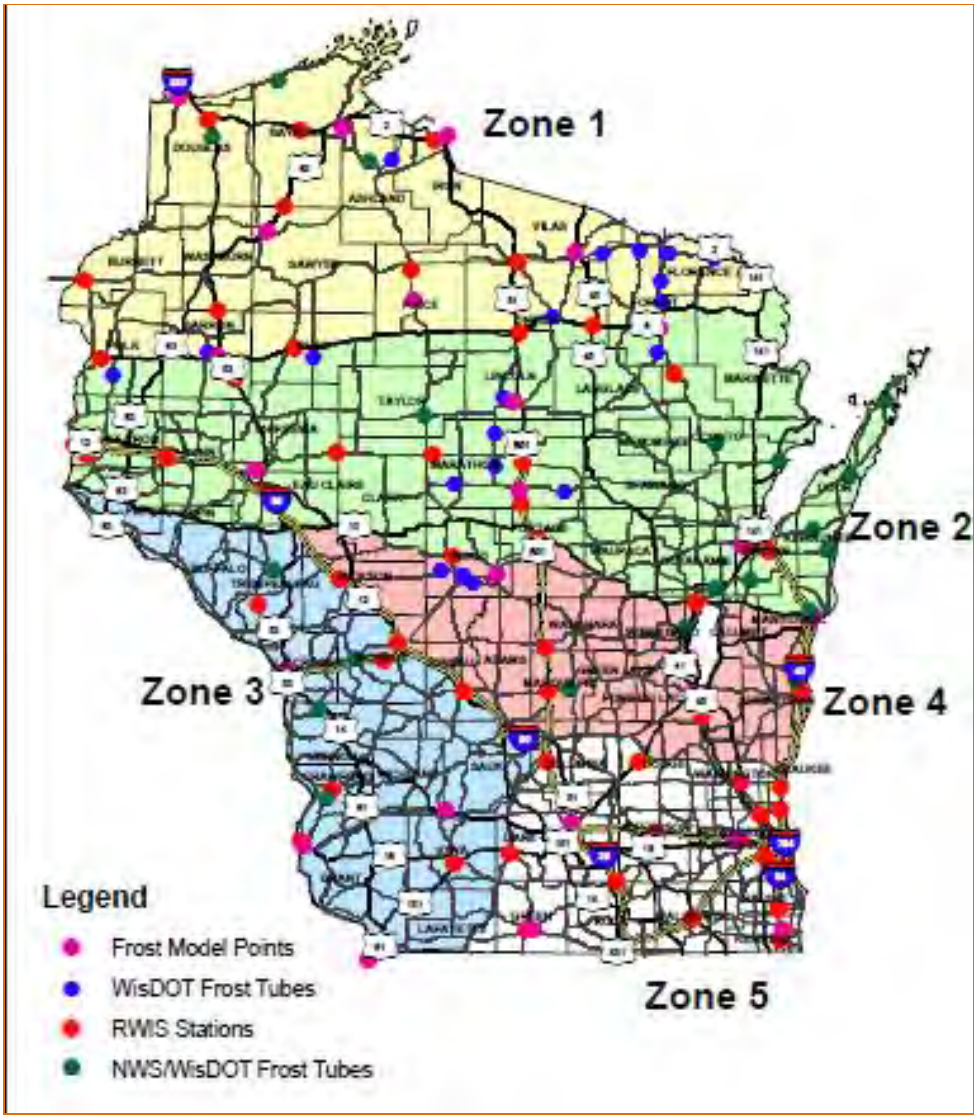


Figure 2.2 Wisconsin Climatological Zones for SLR Analysis (WisDOT 2011a)

2.3.1 Frozen Road Declaration Program

Wisconsin has a year-round weight limit of 80,000 lbs gross vehicle weight with special overweight permits for logging trucks up to 90,000 lbs. In mid-winter, when roads are frozen solid, a 98,000-lb limit without a permit takes effect. Table 2.1 shows the allowable winter weights on frozen roads. The maximum allowable load for a single axle is 23,000 lbs. In addition, the gross weight imposed on the highway by all axles of a vehicle or combination of vehicles is limited to 98,000 lbs.

Table 2.1 Maximum Winter Weight Limitations (WisDOT 2011d)

Distance Front to Rear Axle Centers of Axle Groups, feet (1)	Two Consecutive axles of 2-axle vehicle or 3 vehicle or combination vehicles having 3 or more axles, lbs (2)	Three consecutive axles of 3-axle vehicle or combination having 4 or more axles, lbs (3)	Four consecutive axles of a vehicle (not in combination) having 4 or more axles, lbs (4)	Four consecutive axles of a combination of vehicles having 5 or more axles, lbs (5)
4	38,000			
5	38,000			
6	38,000			
7	46,000*	46,000		
8		46,000		
9		55,000		
10		55,500		
11		56,500		61,500
12		57,000	67,500	62,000
13		61,000 **	72,000	62,500
*Maximum allowed at 7feet or more. **Maximum allowed at 13feet or more.				

The frozen road declaration program starts in mid-December to late February or early March as determined by the Bureau of Highway Operations. The start and end dates for the Frozen Road period are based on a modified frost formula adopted from Minnesota plus data from pavement condition evaluation, frost tube readings, current air and pavement temperatures from WisDOT's Roadway Weather Information System, and the National Weather Service. A frost depth of 18 to 20 inches is used as the criterion to declare a state road as frozen. The history of frozen road declaration is shown in Table 2.2, which indicates that the average date for the beginning of the frozen road period in Wisconsin, based on 27 years (1984-2011) of data, occurs on December 22nd while the 27-year average date for ending the frozen road period is March 4th.

Table 2.2 Wisconsin Frozen Road Declaration History (WisDOT 2011b; 2011c)

Year (1)	Start (2)	End (3)	Extended to (4)	No. of Days (5)	No. of weeks (6)
1983-84	Dec. 19	March 2	March 16	88	13
1984-85	Dec. 17	March 1	March 7	82	12
1985-86	Dec. 16	Feb. 28	March 7	83	12
1986-87	Dec. 8	March 6		88	13
1987-88	Dec. 21	Feb. 26		67	9.5
1988-89	Dec. 19	Feb. 24	March 10	82	12
1989-90	Dec. 18	March 2		75	11
1990-91	Dec. 17	March 1		75	11
1991-92	Dec. 15	March 1		77	11
1992-93	Dec. 21	March 1	March 8	77	11
1993-94	Dec. 20	March 7	Feb. 28	70	10
1994-95	Dec. 26	Feb. 27		63	9
1995-96	Dec. 18	March 4		76	11
1996-97	Dec. 16	March 3		77	11
1997-98	Dec. 22	March 1	Feb. 16	56	8
1998-99	Dec. 14 N. of US 10	March 8	March 1 N. of US 10	84	12
	Dec. 21 S. of US 10	March 1	Feb. 22 S. of US 10	70	10
1999-00	Dec. 27	Feb. 28		64	9
2000-01	Dec. 18 N. of US 10		March 12 N. of Wis 29	83	12
	Dec. 25 S. of US 10	Feb. 26 S. of Wis 29	Feb. 22 S. of US 10	63	9
2001-02	Dec. 31 N. of US 10	March 4	February 25	56	8
	Jan. 7 S. of US 10	March 4	February 25	49	7
2002-03	Dec. 16	March 3	March 17	92	13
2003-04	Dec. 29 N. of US 10	March 1	---	63	9
	Jan. 12 S. of US 10	March 1	---	49	7
2004-05	Dec. 27 N. of US 10	March 7	---	64	9
	Jan. 3 S. of US 10	Feb. 28 S. of Wis 64	---	57	8
2005-06	Dec. 12 N. of US 10		March 13 N. of Wis 29	91	13
	Dec. 19 S. of US 10	March 6 S. of Wis 29		77	11
2006-07	Jan 22	March 12	---	50	7
2007-08	Dec 24	March 24, N of Wis 64	---	91	13
		March 17, S. of Wis 64	---	84	12
2008-09	Dec 22	March 9	---	77	11
2009-10	Dec 20 Zones 1&2	March 4 Zones 2-5	---	55-72	8-10
	Jan 6 Zones 3&4		---		
2010-11	Dec 17 Zones 1-4	---	---		
	Dec. 29 Zone 5	---	---		
27-Yr Average	Dec.22	March 4	---	72	10
27-Yr Range	Dec. 8 – Jan. 22	Feb. 16 – March 24		49-92	7-13

2.3.2 Class II Roads Program

Wisconsin defines a Class II Road as all state highways that are judged to have unstable condition of the roadway subgrade during the period when frost is leaving the ground such that the travel of vehicles with overweight permits would cause undue damage to the highway (WisDOT 2011e). There are approximately 1,400 miles (94 segments) of bituminous highways on the Class II list during the springtime freezing and thawing period. Class II highways currently account for only 12 percent of the state highways. A map showing Class II roads is shown in Figure 2.3. Based on historical weight restriction data, Wisconsin has determined that the 45-year average for imposing spring load restrictions begins on March 9th, while the 45-year average for ending the load restriction occurs on May 9th.

On January 1, 2011, Wisconsin Statute s.348.27(9m)4 was revised to allow WisDOT to issue a special "98k on six axles permit", also known as an RS Permit, for the transport of raw forest products at gross vehicle weight (GVW) of 98,000 lbs on vehicles or vehicle combinations with six or more axles during the spring-thaw suspension period (WisDOT 2011e). The RS Permit is never valid on any segment of Interstate highways but is valid on almost all State and US highways, except for posted roads and bridges, and on city, village, town and county roadways unless such roadway is posted. Class II roads are affected by the Statute in that vehicles and vehicle combinations operating with the RS Permit may transport over Class II highways, but may not exceed posted limits for bridges or culverts.

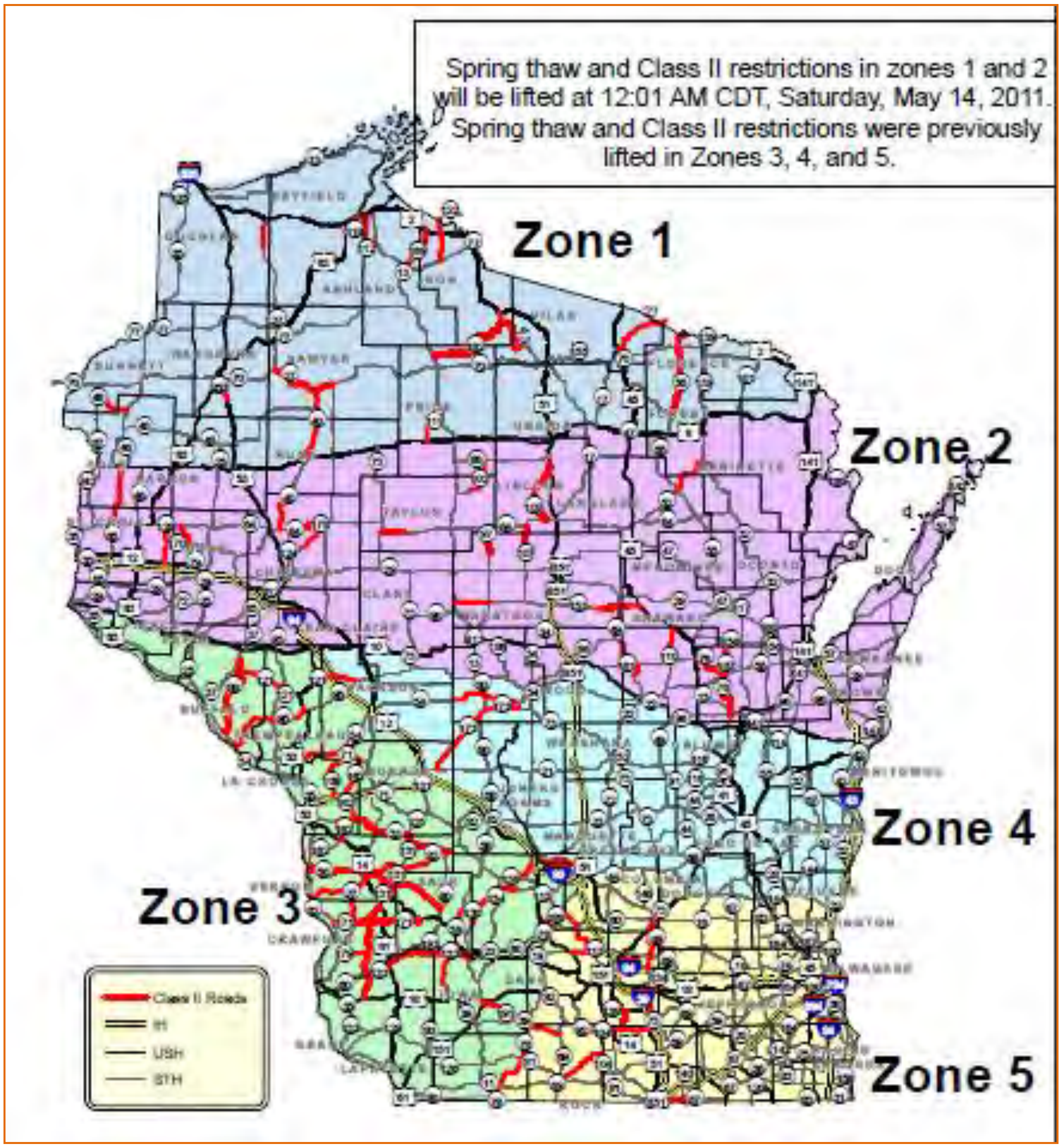


Figure 2.3 Class II Roads within Highway Network (WisDOT 2011e)

2.3.3 Posted Roads

The posted roads program is applicable to roadway sections that are considered too weak to even withstand the legal load limit of 80,000 lbs during the springtime freezing and thawing period. There are approximately 170 miles (13 segments) of state highways that are posted during the springtime freezing and thawing period indicating the allowable weight limits. The 13 segments account for less than 2% of Wisconsin's state highways. The posted program goes into effect during the second week in March until late April or early May. A map showing the most recent posted roads is shown in Figure 2.4.

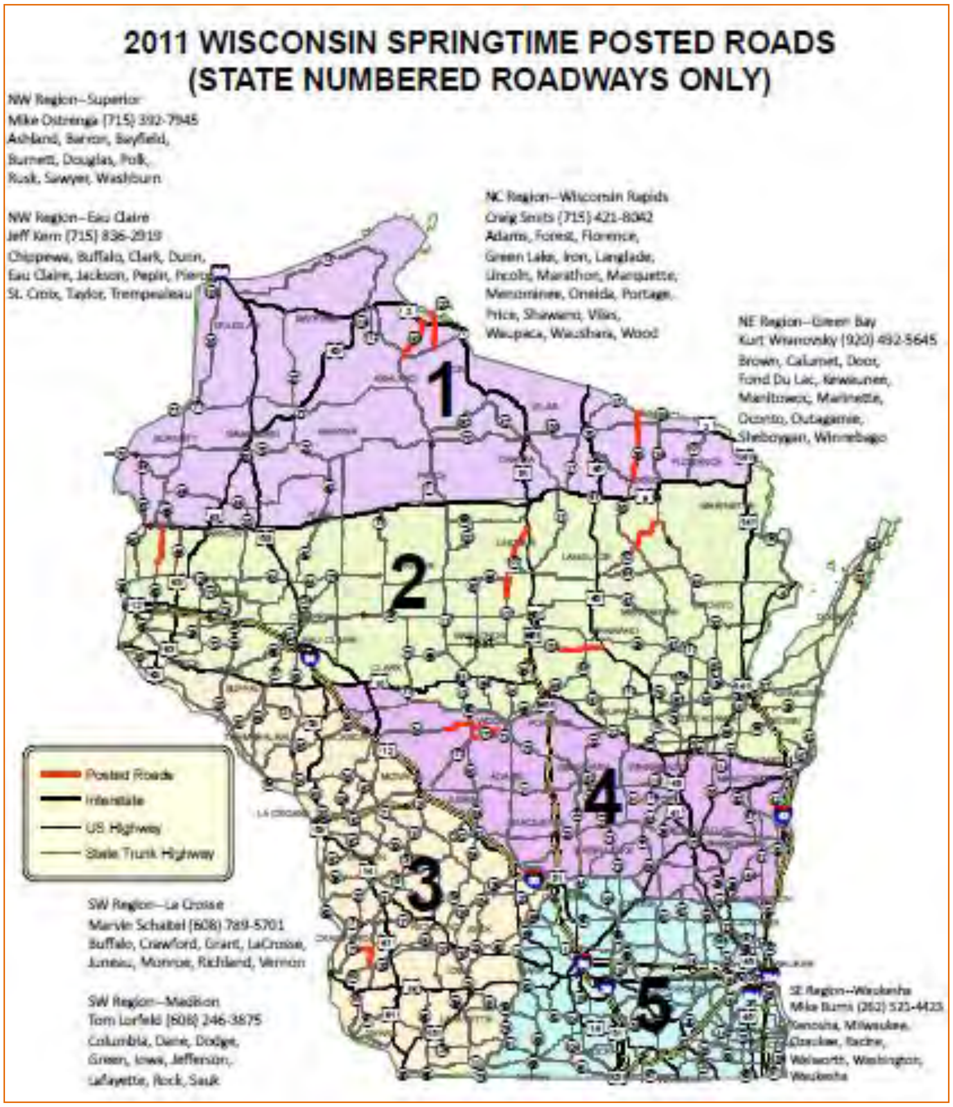


Figure 2.4 Springtime Posted Roads (WisDOT 2011f)

2.4 SLR Practices in Neighboring Midwestern States

A comparison of the average dates for SLR implementation and removal is shown in Table 2.3 for Wisconsin and surrounding states. Almost all states have early March as a start date for the implementation of SLR. SLR in Minnesota mostly occurs on county, township, and municipal roads. No SLR is placed on Interstate Highways. Minnesota is divided into six frost zones on the basis of climate. The SLR start date for each frost zone occurs when the 3-day weather forecast indicates that the cumulative thawing index (CTI) will exceed 25°F degree-days and continued thawing is expected. Minnesota policy does not permit SLR to last more than 8 weeks unless extraordinary conditions exist that require additional time or route specific signage.

Table 2.3 SLR and Removal Dates for Wisconsin and Neighboring States

State (1)	Average Date for Start of Spring Load Restriction (2)	Average Date for End of Spring Load Restriction (3)
Wisconsin	March 9	May 9
Iowa**	March 1	May 1
Michigan**	Early March	Late May
Minnesota (by zone)*		
--North	March 17	May 13
--North-Central	March 16	May 9
--Central	March 12	May 5
--Metro	March 10	April 27
--South	March 8	May 2
--Southeast	March 9	May 3
North Dakota**	March 15	June 1
South Dakota**	February 28	April 27
* Adapted from MnDOT (2011). ** Adapted from Ovik et al. (2000).		

The CTI is calculated as follows:

$$CTI_n = \sum_{i=1}^{n} \left(DTI - DFI / 2 \right) \tag{2.3}$$

where,

CTI_n = Cumulative thawing index calculated over ‘n’ days (° F-day);

DTI = Daily Thawing Index, °F = amount the daily average temperature is above a predetermined reference temperature for the date corresponding to a given day; and

DFI = Daily freezing index, °F = the amount the daily average temperature is below freezing.

2.5 Economic Impacts of SLR

The implementation of seasonal load restrictions during the spring-thaw period is recognized by industry to interrupt the normal transportation of raw materials to processing facilities. For the logging industry in particular, this has major impacts on productivity and costs, but to highway agencies, the restriction is needed to minimize pavement damage caused by heavy logging trucks and extend the useful life of the pavement. Although SLR has been implemented for many years, very few studies have been conducted to examine the benefits and costs associated with SLR.

Wisconsin

Although it did not specifically address SLR, Wisconsin DOT commissioned a truck size and weight study to assess potential changes in Wisconsin’s laws that would benefit the Wisconsin economy while protecting roadway and bridge infrastructure and maintaining safety (Cambridge 2009). A generic comparison of ESALs was made between a conventional five-axle 80,000-lb tractor-semitrailer truck with a 90,000-lb five-axle and six-axle truck. The standard, fully-loaded, five-axle 80,000-lb truck is equivalent to about 2.4 ESALs, while the same truck increased to 90,000 pounds (a 12.5% increase) imparts 4.1 ESALs (a 70.8% increase). A 6-axle tractor-semitrailer at 90,000 lbs has a 2.0 ESAL impact since its weight is distributed over six axles instead of five. An added pavement benefit of a 90,000-lb 6-axle truck is that fewer trips are required to carry the same amount of payload, resulting in almost 30% fewer ESAL miles per payload ton-mile (Cambridge 2009).

Findings of a benefit-cost analysis were reported for standard truck configurations, and in some cases, the heavier trucks generated net statewide benefits. The analysis considered transport savings, pavement costs, bridge costs, safety, and congestion. SLR was not explicitly considered. Heavier truck sizes considered in the analysis included:

- Six-axle 90,000 pound tractor-semitrailer (6a TST 90);
- Seven-axle 97,000 pound tractor-semitrailer (7a TST 97);
- Seven-axle 80,000 pound single unit truck (7a SU 80);
- Eight-axle 108,000 pound double (8a D 108);
- Six-axle 98,000 pound tractor-semitrailer (6a TST 98); and
- Six-axle 98,000 pound straight truck-trailer (6a STT 98).

The benefits and costs of each of the proposed changes from the 2009 TSW report are reported in Table 2.4. The benefits and costs shown in this table are based on the assumption that each candidate truck is implemented by itself. If all of the candidate trucks are implemented, the total benefits and costs for each category would be slightly greater than those shown for the six-axle 98,000-pound tractor-semitrailer. It must be noted that the two six-axle 98,000-lb configurations do not meet the Federal Bridge Formula but are both currently in use for hauling raw forest products. The benefits shown in Table 2.4 assume existing Federal law prohibits operation on the Interstate highway system.

Table 2.4 Benefit-Cost of Heavier Truck Loads (Cambridge 2009)

		System User Benefits			Public Agency Benefits and Impacts			Net Benefits	
Meets Federal Bridge Formula (1)	Configuration (2)	Transport Saving (3)	Safety (4)	Congestion (5)	Pavement (6)	Bridge Costs for TSW Config. (7)	Base-line Bridge Costs (8)	With TSW Bridge Costs Only (9)	With All Bridge Costs (10)
Yes	Base Case	0.00	0.00	0.00	0.00	0.00	(55.50)	0.00	(55.50)
Yes	6a TST 90	5.50	0.46	0.92	2.57	(2.18)	(55.50)	7.26	(48.24)
Yes	7a TST 97	6.27	0.70	0.85	3.87	(3.08)	(55.50)	8.62	(46.88)
Yes	7a SU 80	2.46	0.11	0.08	0.40	(2.26)	(55.50)	0.78	(54.72)
Yes	8a D 108	3.42	0.46	0.49	3.34	(6.02)	(55.50)	1.69	(53.81)
No	6a TST 98	19.19	1.52	1.89	1.10	(8.48)	(55.50)	15.23	(40.27)
No	6a STT 98	2.19	0.09	0.06	0.03	(4.22)	(55.50)	(1.85)	(57.35)
All values in millions (assumes non-Interstate highway operation only).									

A major finding of this study is that five of the six truck configurations reviewed generate net statewide benefits if they are allowed on non-Interstate highways and if the impacts on bridges are limited to the direct impacts of the new truck configurations. Three of the newer truck axle configurations (6a TST 90;

7a TST 97; and 6a TST 98) would generate the highest net benefits. Taking into account the total bridge costs and the ability to operate on the Interstate, the most successful new configuration, in terms of net benefits, is the six-axle 98,000-lb semitrailer (6a TST 98), which generates the highest savings in transport costs, safety, and congestion. However, this truck, while currently operating under exception in Wisconsin, does not meet the Federal Bridge Formula with its commonly-used axle spacing. The next most beneficial truck is the seven-axle 97,000-lb semitrailer (7a TST 97) followed by the marginally beneficial six-axle 90,000-lb semitrailer (6a TST 90).

Minnesota

An analysis of a survey of industry costs, combined with pavement performance and freight demand models, concluded that the benefits of lifting SLR policy in Minnesota outweighed the additional costs (Smalski et al. 2006). The survey analysis defined the economic benefit of removing SLR in terms of the reduction of vehicle kilometers traveled (VKT) or travel time due to the imposition of the SLR policy multiplied by an appropriate operating cost per kilometer or value of time. The economic cost was defined in terms of the net present value of increased maintenance costs resulting from poorer pavement performance. The performance estimate was based on the mechanistic-empirical model software, MnPAVE, which estimated pavement life in terms of rutting failure on Minnesota local roads. MnPAVE was used to estimate the years before rutting failure on a link by link basis for scenarios involving the "with" and "without" implementation of the SLR policy. For most links, the study revealed that the economic benefits without SLR to industry and haulers significantly outweighed the costs of marginally higher damage to local roads. The estimated benefit/cost ratio of lifting the SLR policy on 9-ton roadways is shown in Figure 2.5 for three Minnesota counties. The results indicated that the benefits of lifting the SLR policy on 9-ton roadways exceeded the increased cost of roadway maintenance.

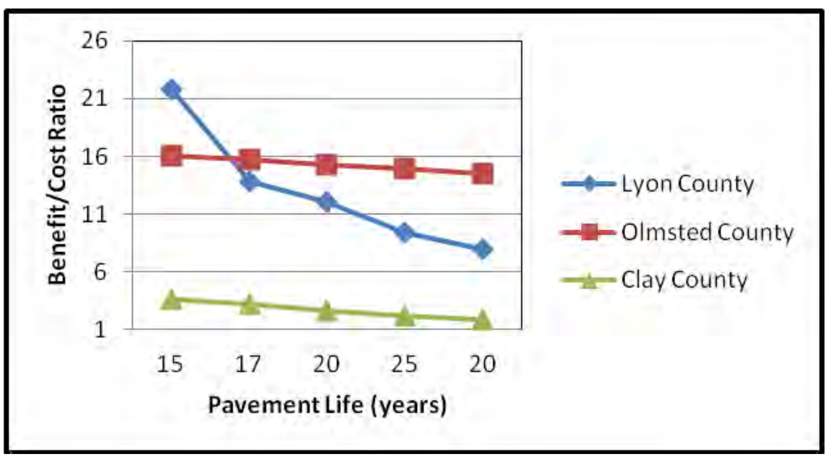


Figure 2.5 Benefit/Cost Ratio of Lifting SLR Policy for Three Minnesota Counties (Smalski et al. 2006)

An earlier study by Ovik et al. (2000), estimated that a typical low-volume asphalt road life will be increased by about 10 percent when the procedure for placing and removing SLR used actual and forecasted average daily temperature. This method was projected to result in a potential savings of more than $10 million annually for Minnesota.

North Dakota

Tolliver and Dybing (2007) studied the impacts of transportation infrastructure on the economy of North Dakota including the effect of SLR. The study estimated that the cost of upgrading the entire state highway system to legal, unrestricted weight was $292 million. The cost to raise all state highway segments to an 8-ton weight restriction was estimated at $141 million, and the cost to raise all segments to a 7-ton weight restriction was estimated at $40 million. The benefits of raising the entire network to legal weight were the transportation cost savings as a result of direct fully loaded movements. For the agricultural sector, it was estimated that elimination of seasonal weight restrictions will result in a reduction of more than 570,000 miles of truck travel at a cost savings of $1.22 million. The benefit to the manufacturing sector was determined to be a reduction of 1.7 million miles of travel, which translated to a cost savings of $1.3 million. A total economic analysis of increasing load limits concluded that the costs associated with eliminating seasonal limits far outweighed the benefits.

Europe

Isotalo (1993) reported on cost savings associated with SLR practices in selected countries with cold climates as presented in Table 2.5. Cost savings ranged from 40 to 92%. Saarenketo and Aho (2005) reported that the extra costs to the forest industry in Finland due to spring thaw weakening was 100 million Euros ($136 million), of which 65 million Euros ($88.4 million) came from public roads. The corresponding cost to the forest industry in Sweden was evaluated to be approximately 100 million Euros ($136 million)/year. The Swedish estimates included extra costs caused by roads with permanent restrictions and extra costs caused by roads with high roughness values. The main reason for extra costs for the paper industry was that timber harvesting could not be arranged to the same degree as production and this forced the industry to use timber storage.

Table 2.5 Cost Savings from SLR of Selected European Countries (Isotalo 1993)

Country (1)	Main Road Sensitive to Frost and Thaw, % (2)	Average Annual Daily Traffic, count (3)	Cost of a Severe Winter with Truck Restrictions, $USD Millions (4)	Cost of a Severe Winter without Truck Restrictions, $USD Millions (5)	Cost Savings, % (6)
Bulgaria	25	2250	200	2500	92.0
CSFR	30	2700	300	2300	87.0
Hungary	40	2900	300	3100	90.3
Poland	15	2240	400	1800	77.8
Romania	50	2700	600	4400	86.4
Yugoslavia	45	2100	900	5400	83.3
France	20	4900	4800	8000	40.0
CSFR = Czech and Slovak Federal Republic					

2.6 SLR Impact on Pavement Performance

Highway pavements deteriorate over time under the combined influence of several factors including traffic loading, pavement layer properties, temperature, drainage conditions, construction, maintenance, and rehabilitation practices. Pavement deterioration is quantified using indicators such as skid resistance, distress in the form of cracking, rutting, potholes, surface roughness as measured by the International Roughness Index (IRI), and structural strength as measured by pavement deflection under a specific load.

For pavements exposed to freeze-thaw cycles, pavement deterioration is accelerated under heavy traffic loading during the spring thaw period because of the structural weakening experienced by the pavement sections. Utterback et al. (1995) reported that asphalt surface break-up, severe potholes, alligator cracking, and early failure of chip seals are commonly observed on asphalt surfaced roads during spring. Janoo and Cortez (2002) concluded that up to 90% of pavement damage occurs during the spring-thaw period. In Minnesota, MacLeod et al. (2002) reported that pavement life can be shortened by 4 to 8% if weight restriction is set a week too late. The life expectancy of the pavement can even be reduced further (by 5 to 12%) if higher winter axle load premiums are removed a week too late. An earlier study by the Federal Highway Administration (1990) reported the relationship between SLR and pavement service life shown in Table 2.6 and concluded that reducing truck weights by 20% between late February and early May can increase the life of vulnerable pavements by 62%. A 50% reduction in the truck weight can result in a 95% increase in pavement life.

Table 2.6 Benefits from Spring Load Restriction (FHWA 1990)

Pavement Load Restriction, % (1)	Pavement Life Increase, % (2)
20	62
30	78
40	88
50	95

The main conditions for the occurrence of spring thaw weakening have been outlined by Saarenkento and Aho (2006) and include:

- Freezing of road and/or subgrade soil;
- Presence of frost susceptible material;
- Availability of enough water at the freezing front;
- Water released by the melting ice during the thawing period stays in road structures or subgrade soils, thus weakening the structure; and
- Road is subject to loads during the thawing period.

There is no risk for spring thaw damage in the absence of any one of the listed factors. The main factors influencing the development of thaw weakening have been further categorized by Saarenkento and Aho (2006) as found in Table 2.7 to include environmental, loading, design related parameters.

Table 2.7 Thaw Weakening Development Factors (Saarenkento and Aho 2006)

Traffic Loading (1)	Environmental (2)	Design (3)
• Amount of heavy vehicles • Magnitude of axle loads • Magnitude of tire pressures • Time between traffic loads	• Weather and hydrological factors • Temperature • Groundwater level precipitation • Frost (ice lenses)	• Drainage, including topography of the road and its surroundings and drainage structures • Road structure thickness, quality and mixture • Subgrade soil and its frost resistance

Kestler et al. (2010) assessed the statistical significance of environmental freeze-thaw related phenomena on cumulative damage to flexible pavements using 21 years of environmental data from two of the eight original flexible pavement test cells at the MnROAD facility. The assessment revealed that damage could generally be modeled as a function of one, two, or three explanatory variables. Thaw depth, or some variation thereof, was a significant explanatory variable for at least each damage model in both test cells evaluated. The combination of the length of the surface freezing season and corresponding average pavement surface temperature appeared to be significant with regard to fatigue cracking for the two test cells analyzed. Both maximum thaw depth and the combination of length of the surface freezing season and air freezing index appear to be significant with regard to rutting.

Raad et al. (1995) evaluated the effects of removing spring load restrictions on two highways (Steese/Elliot and Haines Highways) in Alaska. The research addressed the actual time when FWD pavement response was most critical and estimated the potential damage and strengthening requirements to the study routes if no springtime load restrictions were applied. The results of the study indicated that the loss of pavement strength was most impacted during thaw initiation in the base and least impacted when the thaw reached a depth of approximately 3.5 feet. Ground temperature measurement was, therefore, considered a better indicator than the FWD for estimating timing and duration of the load restriction period. Criteria for using ground temperature data to estimate the load restriction period were developed. Rutting and roughness measurements on the Steese/Elliot Highway indicated that road damage associated with frost heaving and foundation instability due to permafrost thaw seemed to be more significant than load related damage.

The impact of increasing the legal load limit from 80,000 to 97,000 lbs on highway pavements was examined by Peters and Timm (2008). To satisfy the federal bridge formula as well as the legal weights of each axle, the study determined that an additional axle at the trailer rear instead of the typical tandem axle set is required for the 97,000-lb configuration. Using a combination of the MEPDG and a layered elastic pavement analysis program (WESLEA), flexible and rigid pavement structures of various cross-sections were examined for four truck traffic levels (250, 1000, 4500 and 8000 AADTT) and for climatic data representing conditions in the State of Alabama. Simulations were performed using each of the four traffic levels, and for each of the percentages of volume, to change tandem axles to tridems (0%, 5%, 25%, 50%, and 100%). The results of the analysis demonstrated that changing rear 34,000-lb tandem axles to 51,000-lb tridem axles had no effect on pavement performance when the total weight of the traffic stream was held constant.

2.7 Limiting Pavement Damage Using Tire Pressure Control Systems

Tire Pressure Control Systems (TPCS) or Central Tire Inflation (CTI) has in recent years, gained acceptance as useful mechanisms for timber transport. It has been reported that trucks equipped with the appropriate air pressure in tires can reduce the damage to roads through improvement in the management of the tires on the truck to increase the traction.

Bradley (2006) reported the use of TPCS by the Forest Engineering Research Institute of Canada (FERIC) to potentially shorten the SLR on secondary roads by hauling with trucks having TPCS technology. The TPCS as described by Bradley (2006) consisted of an onboard automated system that permits the driver of a vehicle to adjust the pressure of the tires on the vehicle while the vehicle is in motion. Adjustment of the tires results in an increase of the contact area of the tire on the pavement surface, thus allowing the legal weight to be transferred to the pavement and the underlying layers over a comparatively larger area. From 2000 to 2003, FERIC conducted full-scale tests on a variety of thin pavements in British Columbia, where fully loaded log trucks were able to haul during the last three to five weeks of the weight restriction period with no measurable increase in pavement rutting or cracking.

Liu et al. (2011) examined the impacts of reduced tire pressure on strain response of thaw-weakened, low-volume roads in Manitoba, Canada. The study was conducted in the spring and fall of 2009 using a double semitrailer equipped with a semi-automated tire pressure control system. Performing the tests at different loads and speeds and at normal and reduced tire pressures, the tests revealed that when the tire pressure was reduced by 50%, the measured maximum strain at the bottom of the asphalt reduced by an average of 15% to 20%.

2.8 Summary of SLR Practices and Economics

1. SLR Practices vary considerably across freeze-thaw regions in North America and in Europe. In the United States and Canada, there appears to be a shift towards the use of a Cumulative Thawing Index approach and some deflection measurements to determine the start and end dates for SLR.

   Applying restrictions:
   - 52% use inspection and observation.
   - 24% of agencies indicated using some kind of a quantitative method.
   - 24% use a fixed-date method to impose restrictions.

   Removing restrictions:
   - 57% used inspection and observation.
   - 29% reported restrictions to be imposed by date.
   - 14% reported using the quantitative method.

   Wisconsin DOT manages three distinct weight restriction programs including:
   - Frozen road declaration
   - Class II roads, and
   - Springtime posted roads.

   A study in Minnesota reported that pavement life can be shortened by 4 to 8% if weight restriction is set a week too late. Pavement life can be reduced further by 5 to 12% if higher winter axle load premiums are removed a week too late.

2. Heavier Trucks with additional 17,000-lb axle

   A 2008 study in Alabama examined an increase in the legal load limit from 80,000 to 97,000 lbs with an additional axle at the trailer rear, instead of the typical tandem axle set. The study used a combination of the MEPDG and a layered elastic pavement analysis program (WESLEA). Simulation analysis demonstrated that changing rear 34,000-lb tandem axles to 51,000-lb tridem axles had no effect on pavement performance when the total weight of the traffic stream was held constant.

3. Benefit-Cost Analysis

   Wisconsin (2009), without directly considering seasonal load practices, the six-axle 98,000-lb semitrailer (6a TST 98) generates the highest savings in transport costs, safety, and congestion. However, this truck, while currently operating under exception in Wisconsin, does not meet the Federal Bridge Formula with its commonly used axle spacings. The next most beneficial truck is the seven-axle 97,000-lb semitrailer (7a TST 97) followed by the marginally beneficial six-axle 90,000-lb semitrailer (6a TST 90).

Minnesota (2007). Pavement life can be shortened by 4 to 8% if weight restriction is set a week too late. Pavement life can be reduced further to 5 to 12% if higher winter axle load premiums are removed a week too late. An analysis of a survey of industry costs, combined with pavement performance and freight demand models concluded that, the economic benefits to industry and haulers of lifting SLR policy in Minnesota outweighed the additional damage costs to local roads.

North Dakota (2006). The cost to raise all state highway segments to an 8-ton weight restriction was estimated at $141 million, and the cost to raise all segments to a 7-ton weight restriction was estimated at $40 million. For the agricultural sector, it was estimated that elimination of seasonal weight restrictions will result in a reduction of more than 570,000 miles of truck travel at a cost savings of $1.22 million. The benefit to the manufacturing sector was determined to be a reduction of 1.7 million miles of travel, which translated to a cost savings of $1.3 million. A total economic analysis of increasing load limits concluded that the costs associated with eliminating seasonal limits far outweighed the benefits.

FHWA (1990). FHWA reported that reducing truck weights by 20% between late February and early May can increase the life of vulnerable pavements by 62%. A 50% reduction in the truck weight can result in a 95% increase in pavement life.

4. Tire Pressure Control Systems

TPCS are useful in reducing the damage to roads during the spring thaw period. The damage is minimized by increasing the contact area of the tire on the pavement surface, thus, allowing the legal weight to be transferred to the pavement and the underlying layers over a comparatively larger area.

Chapter 3 – Logging Industry Truck Hauling Practices

3.1 Introduction

This chapter describes logging industry truck hauling practices in Wisconsin. A variety of data are assembled in this chapter to document the following: an overview of the logging supply chain; a survey of members of the Great Lakes Timber Professionals Association (GLTPA); interviews of industry professionals at the GLTPA Logging Congress; Wisconsin DNR management of forested lands; commercial land owners of forested property; inventory of logging related industries; and GIS mapping of logging operations in the state. Data and information in this chapter are used to design the field experiment and provide a basis for addressing the study objectives.

3.2 Overview of Logging Supply Chain

Wisconsin highways are exposed daily to a variety of trucks that carry a wide range of raw and finished products in different directions within and across state borders. Hence, identifying specific routes used by logging trucks is a complex task that requires an understanding of logging supply chain operations within the state and the factors that drive the operations. Stewart et al. (2010) identified the logging supply chain to include logging sites, loggers, truckers, railroads, and mills depicting the supply chain as in Figure 3.1.

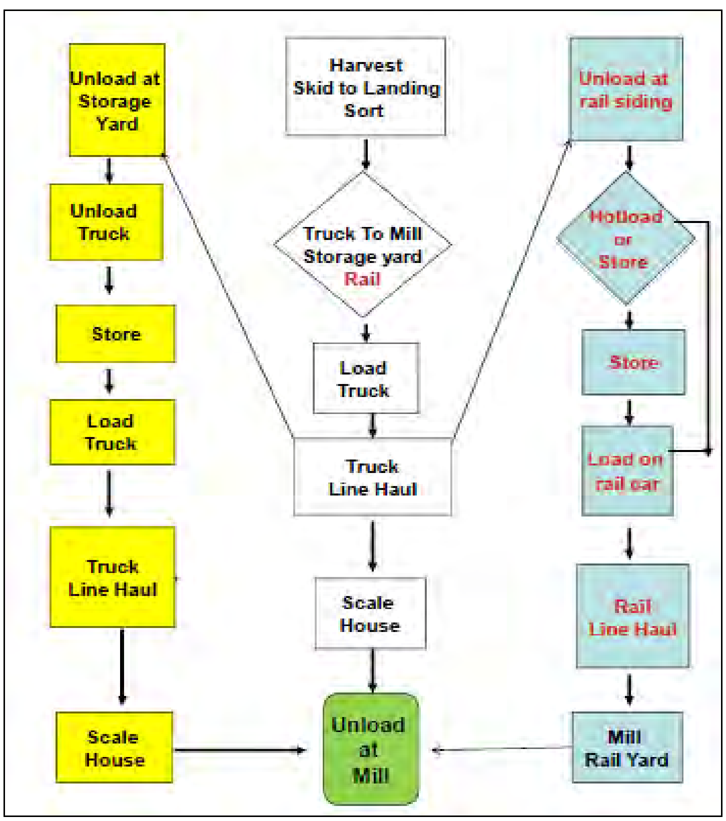


Figure 3.1 Wood Products Supply Chain (Stewart et al. 2010)

Green et al. (2003) summarized logging operations as a five-step process consisting of the following activities:

a) Selecting trees for harvest;
b) Planning of routes and road building;
c) Felling and delimbing of trees;
d) Skidding logs to landing sites for sorting and loading; and
e) Transporting logs to processing facilities.

Trees for harvest are either privately or publically owned and are selected by foresters with the objective of obtaining the maximum value of the harvest while protecting the future productivity of the land. The land owner is paid a stumpage fee for the right to harvest logs from the land. Stumpage is paid by the ton or board-foot measure. Once logs are cut by loggers under the supervision of foresters, skidders are used to pull the logs from the woods to the logging roads for pick up by log haulers. Log haulers are then paid by the weight or volume of wood delivered to the purchaser. Whether it is hauling logs to a storage yard, rail siding or directly to a mill, log haulers often encounter challenges stemming from seasonal weight restrictions that prevent them from driving the most direct route, which directly impacts hauling cost. On average, the total price of logs purchased by the mills is roughly in thirds for stumpage, harvesting, and transporting.

3.3 Great Lakes Timber Professionals Association Survey

A large number of stakeholders are involved in logging supply operations ranging from single truck owner-operators to multi-national corporations. Key stakeholders were identified and planned visits were conducted to determine factors that impact logging supply operations. An identified key stakeholder included the Great Lakes Timber Professionals Association (GLTPA). With cooperation from GLTPA, a survey was drafted and distributed in August 2011 to solicit input from the logging industry to quantify hauling operations and practices. The GLTPA provided valuable assistance to this study in reviewing and inserting a paper survey into the 2011 Logging Congress mailing, as well as emailing the electronic survey file to GLTPA membership. A total 456 members were emailed or sent a survey; 19 surveys were returned representing a 4.4% response rate. A copy of the survey is included as an Appendix.

Primary questions in the survey included size of trucks in the fleet, total number of employees and truck drivers in the firm, facility space, who determines haul routes, how spring load restrictions affect operations, and routing of logging trucks the past two years. Additional information requested included miles driven by the firm and approximate cost per mile for operating each truck. This information was used in the data analysis component of this study.

3.3.1 Impact of Restrictions on Log Hauler Operations

The survey sought to examine how spring load restrictions impact log hauler operations as related to haul route choice, fleet and load management. Not every respondent addressed each of the areas the survey sought. When it comes to haul route choice, 95% (18/19) of respondents reported changing routes during the spring load restriction (SLR) period. A similar percentage of respondents also indicated reducing load to comply with regulations. The load reduction often forces haulers to change vehicle types and also increase the number of trucks. Others commented that the combination of longer routes and vehicle changes prevent them from hauling during the SLR period.

3.3.2 Short-term Impact of Wisconsin Statutes

The survey also attempted to examine the short-term impact of Wisconsin Statute s.348.27(9m)4 (RS Permit Law) on logging operations. It was assumed that with the new law, enacted in January 2011, loggers will take advantage and haul more logs using fewer vehicles and expect a reduction in total vehicle trips and miles traveled, as well as a reduction in operating costs between 2010 and 2011. Twelve respondents provided data on total miles traveled while seven supplied operating cost information. A comparison between 2010 and 2011 operations are shown in Table 3.1. There was not much difference in the total number of average logging trips per day generated between the two time periods but there was an approximately $0.08/mile higher operating cost per mile for 2011. The operating cost difference could have been due to a combination of factors such as variation in log demand destinations being farther in 2011, combined with high fuel prices at the time, or longer detour routes stemming from an initial over-reaction of more local governments posting their roads to avoid a perceived damage anticipated from Wisconsin Statute s.348.27(9m)4, which allows heavier than normal loads to travel on road networks that are not posted.

Table 3.1 Basic Comparative Statistics of RS Permit Law on Logging Operations

Operation (1)	**2010 Hauling Season (2)**	**2011 Hauling Season (3)**
Average logging trips generated/day	12.8 trips/day (Range: 0.20 to 177; n=16)	13.0 trips/day (Range: 0.27 to 177; n=16)
Average miles traveled during SRL period	23,127 miles (Range: 1,000 to 110,000; n=12)	28,354 miles (Range: 1,000 to 160,000; n=12)
Average operating cost/mile ($)	$1.75/mile (Range: 1.40 to 2.85; n=7)	$1.83/mile (Range: 1.35 to 2.85; n=7)

3.3.3 Impact of Logging Firm Size on Logging Trip Generation

The effect of firm size was examined for the purpose of predicting future logging trips per day to be generated by a logging truck firm facility. A firm's facility size was defined in terms of any one of three variables including the number of employees, the gross floor area of office space, and the total number of drivers. The analysis suggested that none of the three variables is a good predictor of the logging trips generated per day.

3.4 Logging Congress

The research team attended the 66th Annual Lake States Logging Congress & Equipment Expo on September 8-10, 2011, in Escanaba, Michigan. Logging Congress is hosted annually by the GLTPA. There are several hundred indoor and outdoor exhibitors at Logging Congress to showcase logging equipment, vendors, suppliers, and display best practices of the industry. It brings together several thousand loggers from throughout the West, upper Midwest and Canada at time when logging production traditionally operates at a reduced level.

The research team rented booth space at the Logging Congress for the purposes of encouraging attendees to complete the logging truck survey and by soliciting input and operational practices from industry to be used in the data analysis.

Annotated notes from the congress are summarized by attendee, and provide a basis for the field evaluation and analysis. Attendee names are not provided to protect their identity:

Attendee #1 - Log hauler in U.P. Michigan

- Pricing at certain mills are a combined $/cord and $/mile. One mill pays the logger $10 to $15 per cord, plus $0.20/mile (one cord = 4' x 8' x 4'). Haulers submit bids to certain mills.
- Truck engines in Michigan have more horsepower and fuel consumption to pull heavier loads (e.g., 475 hp). There is little difference pulling Michigan and Wisconsin weight loads.
- Michigan logging season generally begins after the first frost in October when sap begins to run and reduce log weight. This condition is preferred by the mills. The season generally ends in March when it becomes difficult to drive in thawing soil; however, hauling from landings may continue.
- Monday through Friday hauling is common, while a few mills operate 24/7. Saturday operations are generally mulch or chips from logging during the weekdays

Attendee #2 - Log hauler from east central Wisconsin

- Load limits vary among counties and roadways presenting a challenge for routing logging trucks. For example, Waupaca County posts all county bridges at 45,000 lbs, which is lower than posted limits of neighboring counties. Shawano County weight restriction is 80,000 lbs. Hauling on I-39 and US 51 in the center of the state presents a challenge where the U.S. highway portion allows 98,000 lbs while the Interstate segment only allows 80,000 lbs (or 90,000 lbs with a permit).

Attendee #3 - Log hauler from north central Wisconsin.

- Load limit discrepancies between counties create a problem routing trucks. For example, Langlade County allows 98,000 lbs while neighboring Lincoln County permits 80,000 lbs. This creates logistical issues transporting logs to Wausau Homes in Weston, and Green Bay Homes in Green Bay.

Attendee #4 - Forester from western U.S. and Wisconsin

- Logging production has increased with advancements in technology and innovations to logging equipment, such as fallers, skidders, and forwarders. Electronic coders can semi-automate cutting of logs to exact lengths (8 feet, 10 feet, etc.). Cutting to precise length is important to sawmills to minimize re-cutting and minimize waste. Felling is cutting to full length, while harvesting is cutting to lengths of 8', 10', or 12'.
- Cost of chipping ranges from $28/ton to $30/ton. New larger skidders cost $275,000.
- Average haul distances vary by region of the country. Western U.S. may average 100 miles, while the Midwest and East regions may range from 30 to 50 miles.

Attendee #5 - Log hauler from U.P. Michigan

- Landings to temporarily store wood for later hauling or transloading to rail cars are important to collect loads from local roads with weight restrictions. It is possible to haul anytime of the year from landings, such as during spring thaw, unlike from the woods.
- Michigan paper mills include:

  Iron Mountain = Verso
  Escanaba = New Page
  Manistique = Manistique Papers (this mill is closing)
  Newberry = Besse and Louisiana Pacific
  Gaylord (Southern Penninsula) = Georgia Pacific
  Marquette = Tullila Sawmill
  KI Sawyer Air Base = Potlatch
  Sagola = Louisiana Pacific

Attendee #6 - Log hauler from northeast Wisconsin

- Border hauling from Wisconsin to Michigan (or back) presents a permit challenge. Hauling from Wisconsin to Michigan requires one plate. Hauling from Michigan to Wisconsin requires two plates. This does not allow for backhaul. Overweight fine is about $500 for exceeding weight limit with a 98,000-lb truck.
- Truck licensing cost varies between states. Michigan truck license is $150 annually. Wisconsin truck license restricted is $900 plus insurance. Wisconsin truck license apportioned is $1,000 plus.
- Fuel consumption can be managed with tire pressure and truck speed. There is an estimated loss of 0.3 mpg with a 100-psi rated tire that is inflated to 90 psi. This translates to about $400/year added fuel costs. There is also an estimated 0.5 mpg loss with extra 10 mph speed when increasing from 55 to 65 mph.

Attendee #7 - Log hauler from northeast Wisconsin

- Border hauling from Michigan to Wisconsin is more problematic than the other direction. This operator drops log loads in Michigan then reloads with a Wisconsin truck to haul finished lumber back into Wisconsin.
- Michigan log haulers generally do not want to travel into Wisconsin with additional restrictions. They are unable to use increased truck capacity allowed in Michigan (up to 162,000 lbs).

3.5 Wisconsin Department of Natural Resources

The Forestry Division of the Wisconsin Department of Natural Resources (DNR) was initially contacted to seek information regarding public lands designated for logging, as well as the harvest volumes and directional distribution of logs in Wisconsin. A forest resource analyst in the Forestry Division recommended that contact be made with the Northern Research Station Forest Inventory and Analysis (FIA) unit of the United States Department of Agriculture (USDA) Forest Service. The FIA is responsible for creating and maintaining a comprehensive forest inventory for 24 States including Wisconsin, Connecticut, Delaware, Illinois, Indiana, Iowa, Kansas, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Nebraska, New Hampshire, New Jersey, New York, North Dakota, Ohio, Pennsylvania, Rhode Island, South Dakota, Vermont, and West Virginia.

The most recent data obtained from the Northern Research Station FIA unit in St. Paul, MN, indicated that 250,186,480 cubic feet of roundwood was harvested in Wisconsin in 2008. Six counties accounted for 73.2% of the in-take of the roundwood and are shown in Figure 3.2 with Wood County receiving approximately 34.6% of the total roundwood harvested in Wisconsin.

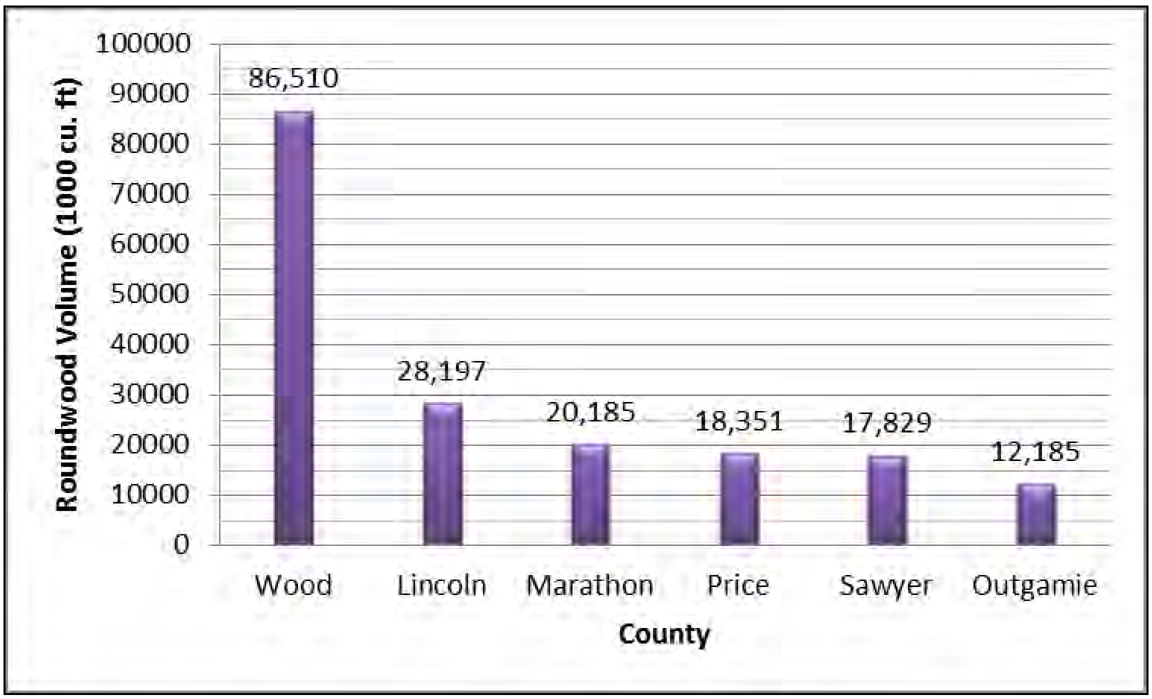


Figure 3.2 Counties Receiving the Bulk of Harvested Roundwood in Wisconsin

The data also revealed that it would have taken approximately 23 counties generating the most roundwood to meet the roundwood demand of the six highest intake counties. The 23 counties supplying the most roundwood and their distribution to the six high intake counties are shown in Table 3.2. Wood County used approximately 68% of the roundwood that it produced internally compared to the other high in-take counties. With the exception of Outagamie County, the other four counties' use of internally generated roundwood varied from 7.7% for Price County to 45.9% for Lincoln County. This important data can assist Wisconsin DOT in identifying, by county, key destinations of raw forest products.

Table 3.2 Roundwood Volume Demand and Supply for High Intake Counties

County	Volume Generated (1000 cu. ft.)	Cum. Volume Generated (1000 cu. ft.)	Cum %	Generated Volume Distribution to High Roundwood Demand Counties (1000 cu. ft.)						
				Wood	Lincoln	Marathon	Price	Sawyer	Outagamie	Total
Langlade	15,182	15,182	6	3,648	2,201	1,736	283	0	686	8,556
Sawyer	12,753	27,935	11	5,414	322	127	1,091	3,864	41	10,862
Lincoln	12,231	40,167	16	2,425	5,614	2,385	561	24	89	11,101
Forest	11,278	51,446	20	3,096	470	717	590	0	681	5,556
Oneida	10,398	61,844	24	2,084	3,698	1,378	1,053	33	268	8,517
Price	10,292	72,137	28	4,180	3,161	530	794	590	161	9,418
Vilas	8,733	80,870	32	2,171	2,059	649	1,444	25	216	6,566
Menominee	8,700	89,571	35	1,991	1,112	1,229	200	0.00	596	5,131
Marinette	8,560	98,132	39	2,120	178	348	901	0.00	1,805	5,355
Bayfield	8,455	106,588	42	2,684	114	173	1,835	2,478	136	7,423
Marathon	8,293	114,881	45	1,955	1,064	2,895	268	1	71	6,256
Jackson	7,557	122,438	48	5,836	51	104	390	43	4	6,431
Oconto	7,512	129,951	51	2,360	157	284	841	0	1,662	5,306
Rusk	6,476	136,427	54	3,508	486	41	310	1,271	5	5,623
Washburn	6,435	142,863	57	1,129	53	59	390	2,561	987	5,181
Taylor	6,203	149,066	59	2,159	1,209	1,087	373	347	0	5,178
Adams	6,149	155,215	62	3,329	746	1,258	227	2	63	5,628
Clark	5,887	161,103	64	3,419	410	442	193	54	9	4,529
Douglas	5,499	166,603	66	1,930	14	377	878	1,597	12	4,811
Shawano	5,164	171,767	68	828	233	658	469	0	446	2,636
Florence	5,014	176,782	70	1,652	61	104	502	0	481	2,801
Burnett	4,830	181,612	72	1,249	1,146	2	383	1,389	294	4,465
Wood	4,690	186,302	74	3,197	138	225	244	96	27	3,930
Total	186,302			62,376	24,707	16,820	14,232	14,384	8,750	141,271

3.6 Industry Lands

A meeting was held with a large owner of forested lands to document the management of private forestry lands in Wisconsin, along with related practices in Upper Peninsula Michigan, and northern and southern Minnesota. The primary purpose of the meeting was to address a fundamental objective of this study, namely assisting the Wisconsin DOT with tools to identify key destinations/sources of the raw forest products in the state.

The meeting with the industry land owner disclosed that seasonal variations affect where the wood comes from within Wisconsin. The areas with more cohesive soils allow for more flexibility in the haul routes as the logging companies will then have a greater selection of routes to choose from during spring thaw. It was stated that it may be advisable to examine the geographic soil regions of Northern Wisconsin to determine the base quality of the current roads; in doing so, this process may narrow the scope of the study area.

The meeting also disclosed that tree species is an important factor in the determination of destinations/sources for the raw forest products. With 23 commercial types of trees present in Wisconsin forests, the logging companies are drawn to the wood necessary for their products. Based on productivity guidelines from Managed Forest Lands laws, the rotation age for most hardwoods (including Red Pine) is at least 60 years.

3.7 Mills, Landings, and Railroad Loadouts

Destinations of haul trucks were the next industry resource collected and synthesized for the initial phase of the study. The primary destination of loaded log trucks are pulp, paper, and saw mills within the state and along the Michigan and Minnesota borders. Some log shipments are exported via rail, such as to Canada, Tennessee, or Virginia. Other destinations include landings (temporary storage of logs) and railroad loadout facilities. Information concerning these destinations was compiled from four meetings with the larger pulp mills in the state and a review of published on-line literature.

Table 3.3 presents pulp and paper mills in Wisconsin, including the mill name, parent company, location, products, and operational status. There are a total of 56 pulp and paper mills in the state (Center for Paper Business 2011). A majority of the mills are operating; however, the economic downturn, regulations, and shifting markets have caused other mills to close. Certain mills convert logs to pulp and eventually paper and other products, while other mills purchase the processed pulp in a bale configuration from one mill and then manufacture the paper.

Table 3.3 Pulp and Paper Mills in Wisconsin (Center for Paper Business 2011)

Mill Name (1)	Parent Company (2)	City (3)	County (4)	Products (5)	Status (6)	Pulp Mill (7)
AIM Demolition USA	NewPage Corp. (Cerberus Capital Mgt.)	Kimberly	Outagamie	Ctdfs(295), Ctdgw(160)	Closed	Y
American Tissue Mills of WI	American Tissue	Tomahawk	Lincoln	Tissue(8)	Operating	-
Appleton Coated LLC	Appleton Coated	Combined Locks	Outagamie	Ucfs(360), Ctdfs(185)	Operating	Y
Badger Paper Mills	Badger Paper Mills	Peshtigo	Marinette	Ucfs(79)	Closed	-
Beloit Box Board Co., Inc.	Beloit Box Board Co., Inc.	Beloit	Rock	Recybrd(21)	Operating	-
Cascades Inc.	Cascades Tissue Group	Eau Claire	Eau Claire	Tissue(55)	Operating	Y
Cellu Tissue Neenah Mill	Clearwater Paper	Neenah	Winnebago	Tissue(100)	Operating	-
CityForest Corp Cellu Tissue	Clearwater Paper	Ladysmith	Rusk	Tissue(49)	Operating	Y
Corenso North America	Corenso	Wisconsin Rapids	Wood	Ucfs(NA)	Operating	-
Domtar Industries Inc.	Domtar Industries Inc.	Rothschild	Marathon	Ucfs(150)	Operating	Y
Domtar Industries Inc.	Domtar Industries Inc.	Nekoosa	Wood	Ucfs(218)	Operating	Y
Domtar Industries Inc.	Domtar Industries Inc.	Port Edwards	Wood	Ucfs(174)	Closed	Y
EcoFibre, Inc.	EcoFibre, Inc.	De Pere	Brown	Pulp(35)	Operating	Y
Fibreform Containers	Fibreform Containers	Germantown	Washington	Spepack(NA)	Operating	-
Filter Materials	Filter Materials (Gusmer Enterpr.)	Waupaca	Waupaca	Spepack(5)	Operating	Y
Flambeau River Papers	Flambeau River Papers	Park Falls	Price	Ucfs(140)	Operating	Y
Fox Valley Fiber	Ponderosa Fibres of America	Oshkosh	Winnebago	Pulp(77)	Operating	-
Geo A Whiting Paper	Geo A Whiting Paper	Menasha	Winnebago	Ucfs(10)	Operating	-
Georgia-Pacific	Georgia-Pacific	Ashland	Ashland	Tissue(22)	Idle	-
Georgia-Pacific.	Georgia-Pacific	Green Bay	Brown	Tissue(425)	Operating	Y
Georgia-Pacific	Georgia-Pacific	Phillips	Price	Const(NA)	Operating	-
Georgia-Pacific.	Georgia-Pacific	Superior	Douglas	Const(51)	Operating	-
Georgia-Pacific	Georgia-Pacific	Green Bay	Brown	Tissue(175)	Operating	-

Table 3.3 (cont.) Pulp and Paper Mills in Wisconsin (Center for Paper Business 2011)

Mill Name (1)	Parent Company (2)	City (3)	County (4)	Products (5)	Status (6)	Pulp Mill (7)
Globe Building Materials	Globe Building Materials	Cornell	Chippewa	Const(73)	Operating	-
Green Bay Packaging	Green Bay Packaging	Green Bay	Brown	Liner(225)	Operating	-
Kimberly-Clark	Kimberly-Clark	Marinette	Marinette	Tissue(75)	Operating	-
Louisiana-Pacific	Louisiana-Pacific	Tomahawk	Lincoln	Ucfs(NA)	Operating	
MeadWestvaco	MeadWestvaco	Menasha	Winnebago	Ucfs(35)	Closed	-
Neenah Paper	Neenah Paper	Appleton	Outagamie	Ucfs(35)	Operating	-
Neenah Paper	Kimberly-Clark	Neenah	Winnebago	Ucfs(80)	Operating	-
Neenah Paper	Neenah Paper	Stevens Point	Portage	Ucfs(80)	Operating	-
NewPage	NewPage (Cerberus Capital Mgt.)	Appleton	Outagamie	Pulp(30)	Closed	-
NewPage	NewPage	Stevens Point	Portage	Ctdgw(230)	Closed	Y
NewPage	NewPage	Wisconsin Rapids	Wood	Ctdfs(550), Ctdgw(405)	Operating	-
NewPage	NewPage	Wisconsin Rapids	Wood	Pulp(401)	Operating	-
NewPage	NewPage	Stevens Point	Portage	Spepack(160)	Operating	-
NewPage	NewPage	Wisconsin Rapids	Wood	Ctdfs(430)	Operating	-
Niagara Development	Niagara Development	Niagara	Marinette	Ctdgw(195)	Closed	Y
P.H. Glatfelter Co.	P.H. Glatfelter Co.	Neenah	Winnebago	Ucfs(125)	Closed	-
Packaging Corporation of America	Packaging Corporation of America	Tomahawk	Lincoln	Corru(520)	Operating	Y
Procter&Gamble Paper Products	Proctor&Gamble	Green Bay	Brown	Tissue(NA)	Operating	-
Procter&Gamble Paper Products	Proctor&Gamble	Green Bay	Brown	Tissue(229)	Operating	-
Riverside Paper	Riverside Paper	Appleton	Outagamie	Ucfs(77)	Closed	-
SCA Tissue North America	SCA Tissue (Svenska Cellulose)	Menasha	Winnebago	Tissue(220)	Operating	Y
Shawano Specialty Papers	Little Rapids	Shawano	Shawano	Tissue(56)	Operating	-

Table 3.3 (cont.) Pulp and Paper Mills in Wisconsin (Center for Paper Business 2011)

Mill Name (1)	Parent Company (2)	City (3)	County (4)	Products (5)	Status (6)	Pulp Mill (7)
Sonoco Products	U.S. Paper Mills Corp. (previous owner)	De Pere	Brown	Recybrd(35)	Operating	-
Sonoco Products	Sonoco Products	Menasha	Winnebago	Corru(50), RecBrd(13)	Operating	-
ST Paper	ST Paper	Oconto Falls	Oconto	Tissue(68)	Operating	Y
Thilmany Papers Nicolet Mill	Packaging Dynamics	Kaukauna	Outagamie	Spepack(200)	Operating	Y
Thilmany Papers Nicolet Mill	Packaging Dynamics	De Pere	Brown	Spepack(65)	Operating	-
Ward Paper	Ward Paper (International Paper)	Merrill	Lincoln	Ucfs(37)	Closed	-
Wausau Paper	Wausau Paper	Brokaw	Marathon	Ucfs(120)	Operating	-
Wausau Paper	Wausau Paper	Mosinee	Marathon	Tissue(113), Spepack(113)	Operating	Y
Wausau-Mosinee Paper	Wausau-Mosinee Paper	Rhinelander	Oneida	Spepack(165)	Operating	-
Wisconsin Paperboard	Newark Group	Milwaukee	Milwaukee	Spepack(152)	Operating	-

Const = Construction materials made of paperboard or pulp; Roofing felt, dry roofing, fiber ceiling, mineral ceiling decorative tile, hardboard, flooring felt, industrial board, insulation board, masonite, panel, deadening felt.

Corru = Corrugating medium; Unbleached kraft paperboard used as the corrugating material in corrugated containerboard (cardboard box).

Ctdfs = Coated free sheet; Coated printing paper made from bleached chemical pulp for high-end commercial applications (reports, sales brochures).

Ctdgw = Coated groundwood; Coated printing and writing paper containing 10 to 65% of mechanical pulp; used for magazines, catalogs, advertising brochures.

Liner = Linerboard; Unbleached kraft paperboard used for the flat facing material in corrugated cardboard boxes.

Pulp = Market pulp; Pulp produced at one location, to be sold and used at another location to make paper or board; includes bleached paper-grade chemical pulp, deinked (recycled) pulp, dissolving pulp, cotton linter pulp.

RecBrd = Recycled paperboard; Paperboard made exclusively from recycled fiber.recycled fiber.

Spepack = Specialty Packaging; Pressure sensitive release paper, food wrapping paper, wax paper, flexible packaging paper, label paper, gasket and filter paper, electrical insulation paper, photo paper, latex saturated paper, cellulose twisting papers, molded pulp containers (egg cartons, etc.), protective padding, etc.

Tissue = Tissue and sanitary paper; Paper toweling, facial tissue, bathroom tissue, napkins, diapers, absorbing papers.

Ucfs = uncoated free sheets; uncoated printing and writing paper made from bleached chemical pulp; used for copy machines, letter writing.

(value) = Capacity of product produced at the mill in 1,000 Short Tons in 2007.

Numerous mills listed in Table 3.3 are located in regions with high-end pavement designs, in particular PCC pavements. These locations primarily in the Chippewa and Fox River Valleys present difficulty in assessing the seasonal effect of logging trucks on asphalt pavements. There are, of course, asphalt pavements in these regions; however, surveys and meetings with the industry disclosed that many 98,000-

lb 6-axle trucks would be routing on PCC pavements in the vicinity of these mills. In addition, some mills are in the southern region of the state, beyond the scope of the study. As a result, several mills were removed from consideration for field pavement evaluation, as shown in Table 3.4. However, these removed mills are a destination for many log loads originating in the northern region of the state and vital to the generation of loaded and empty trucks.

Table 3.4 Pulp and Paper Mills Removed from Field Experimentation

Mill Name (1)	City (2)	County (3)	Products (4)	Pulp Mill (5)
(a) Chippewa River Valley with concentration of PCC pavement				
Globe Building Materials	Cornell	Chippewa	Const(73)	-
Cascades Inc.	Eau Claire	Eau Claire	Tissue(55)	Y
(b) Fox River Valley with concentration of PCC Pavement				
Appleton Coated LLC	Combined Locks	Outagamie	Ucfs(360), Ctdfs(185)	Y
Cellu Tissue Neenah Mill	Neenah	Winnebago	Tissue(100)	-
EcoFibre, Inc.	De Pere	Brown	Pulp(35)	Y
Fox River Fiber	De Pere	Brown	Pulp(77)	Y
Fox Valley Fiber	Oshkosh	Winnebago	Pulp(77)	-
Geo A Whiting Paper	Menasha	Winnebago	Ucfs(10)	-
Georgia-Pacific Corp.	Green Bay	Brown	Tissue(425)	Y
Georgia-Pacific Corp.	Green Bay	Brown	Tissue(175)	-
Green Bay Packaging	Green Bay	Brown	Liner(225)	-
Neenah Paper	Appleton	Outagamie	Ucfs(35)	-
Neenah Paper	Neenah	Winnebago	Ucfs(80)	-
Procter&Gamble	Green Bay	Brown	Tissue(229)	-
SCA Tissue North America	Menasha	Winnebago	Tissue(220)	Y
Sonoco Products	De Pere	Brown	Recybrd(35)	-
Sonoco Products	Menasha	Winnebago	Corru(50), RecBrd(13)	-
Thilmany Papers Nicolet Mill	Kaukauna	Outagamie	Spepack(200)	Y
Thilmany Papers Nicolet Mill	De Pere	Brown	Spepack(65)	-
(c) East Central Region with concentration of PCC pavement				
Kimberly-Clark	Marinette	Marinette	Tissue(75)	-
ST Paper	Oconto Falls	Oconto	Tissue(68)	Y
Shawano Specialty Papers	Shawano	Shawano	Tissue(56)	-
Filter Materials	Waupaca	Waupaca	Spepack(5)	Y
(d) Southern Region beyond scope of project				
Fibreform Containers	Germantown	Washington	Spepack(NA)	-
Beloit Box Board Co., Inc.	Beloit	Rock	Recybrd(21)	-
Wisconsin Paperboard	Milwaukee	Milwaukee	Spepack(152)	-

Removing the operational mills in Table 3.4 in the vicinity of PCC pavements presents a clearer picture of those mills in concentrated areas of asphalt pavements. Meetings with pulp and paper mill staff identified those mills that receive (or do not receive) 98,000-lb 6-axle log loads during spring thaw, and the possibility of using scales to collect truck weight and axle weight data. Tables 3.5 and 3.6 identify mills receiving or not receiving 98,000-lb 6-axle log loads, respectively. There are PCC pavements in the vicinity of these mills; however, primary and secondary roads around the mills are predominantly asphalt pavement.

Table 3.5 Pulp and Paper Mills receiving 98,000-lb Log Trucks on Asphalt Pavements

Mill Name (1)	City (2)	County (3)	Products (4)	Use of Scale (5)
(a) Flambeau River Valley				
Flambeau River Papers	Park Falls	Price	Ucfs(140)	N/A
Georgia-Pacific Corp.	Superior	Douglas	Const(51)	N/A
(b) Wisconsin River Valley Region				
Domtar Industries Inc.	Rothschild	Marathon	Ucfs(150)	Y
Domtar Industries Inc.	Nekoosa	Wood	Ucfs(218)	Y
NewPage	Wisconsin Rapids	Wood	Ctdfs(550), Ctdgw(405)	Y
NewPage	Wisconsin Rapids	Wood	Ctdfs(430)	Y
Packaging Corporation of America	Tomahawk	Lincoln	Corru(520)	Y

Table 3.6 Pulp and Paper Mills not receiving 98,000-lb Trucks on Asphalt Pavements

Mill Name (1)	City (2)	County (3)	Products (4)	Use of Scale (5)
(a) Wisconsin River Valley that do not operate 98,000 lb during Spring Thaw				
Wausau Paper	Mosinee	Marathon	Tissue(113), Spepack(113)	N
NewPage – Biron	Wisconsin Rapids	Wood	Pulp(401)	Y
(b) Wisconsin River Valley that do not operate 98,000 lb (receive processed pulp)				
American Tissue Mills	Tomahawk	Lincoln	Tissue(8)	N/A
Georgia-Pacific Corp.	Phillips	Price	Const(NA)	N/A
Louisiana-Pacific	Tomahawk	Lincoln	Ucfs(NA)	N/A
Wausau Paper	Brokaw	Marathon	Ucfs(120)	N
Wausau-Mosinee Paper	Rhinelander	Oneida	Spepack(165)	N
(c) Flambeau River Valley				
CityForest Corp Cellu Tissue	Ladysmith	Rusk	Tissue(49)	N/A

Another primary destination of raw forest products is sawmills. Reviewed literature and furnished DNR data assisted in identifying all sawmills in the state; there are an estimated 411 mills, ranging from large corporations to small family-owned businesses (Wisconsin DNR 2011). Table 3.7 lists 12 of the largest sawmills in the state based upon 1,000 board-feet produced annually (1,000 Board-Feet = 1 MBF). These mills annually exceed 11,000 MBF and require frequent delivery of logs to maintain production levels.

Although this list does not include all mills, it does identify primary sources of heavy logging trucks and appropriate locations for evaluation of asphalt pavement impacts.

Table 3.7 Largest Sawmills in Wisconsin Exceeding 11 Million Board-Feet Annually

Firm (1)	City (2)	County (3)	Type (4)
Biewer Wisconsin Sawmill	Prentice	Price	Sawmill
Goodman Veneer & Lumber Co.	Goodman	Marinette	Sawmill
Kretz Lumber Company Inc.	Antigo	Langlade	Sawmill
Marion Plywood Corp.	Marion	Waupaca	Veneer
Meister Lof & Lumber Co.	Reedsburg	Sauk	Sawmill
Menominee Tribal Enterprise	Neopot	Menominee	Sawmill
Nelson Hardwood Lumber	Prairie du Chien	Crawford	Sawmill
Northwest Hardwoods Sawmill	Dorchester	Clark	Sawmill
Ort Lumber, Inc.	New London	Outagamie	Sawmill
Park Falls Hardwoods	Park Falls	Price	Sawmill
Pukall Lumber Co., Inc.	Woodruff	Vilas	Sawmill
Webster Lumber Co.	Bangor	Lacrosse	Sawmill

Railroad sidings and landings (log staging locations) also pose an important source for log truck trips. Meetings with pulp and paper mill companies identified larger landings and railroad sidings used actively for transloading and moving logs towards the mills. There are several smaller rail sidings along the Canadian National Railway in northcentral and northwest Wisconsin, and along the Escanaba & Lake Superior Railroad in the northeast. NewPage Corporation operates several large landings in northern Wisconsin, while Domtar Industries and Thilmany Papers favor railroad sidings to transport logs to mills in the Wisconsin River Valley and Fox River Valley, respectively. Table 3.8 lists NewPage Corp. landings active in northern Wisconsin that receive 98,000-lb 6-axle log trucks during spring thaw. Rail sidings for Domtar and Thilmany are shown in Table 3.9. All paper companies expressed cooperation for the use of weigh scales at these facilities for research purposes.

Table 3.8 NewPage Landings with 98,000-lb Trucks during Spring Thaw

City (1)	County (2)	Truck Frequency during Spring Thaw (3)	Transload logs to rail cars (4)	Use of Scale for Research (5)
Parkland (Superior)	Douglas	50 per week**	Y	Y
Ashland (south)	Ashland	N/A	Y	Y
Fifield	Price	10 to 15 per week	Y	Y
Ladysmith	Rusk	30 to 40 per week	N	Y
Monaco	Oneida	10 to 15 per week	N	No Scale
Pembine*	Marinette	100 per week	Y	No Scale
* Weights of truck enroute to Wis. Rapids can be measured at mill scale ** Projected to be higher in 2011-2012 with storm damage in Burnett & Washburn County				

Table 3.9 Railroad Sidings with 98,000-lb Trucks during Spring Thaw

Mill (1)	City (2)	County (3)	Truck Frequency during Spring Thaw (4)	Use of Scale for Research (5)
Domtar	Exeland (Weirgor)	Rusk	25 per week*	Y
Thilmany	Stanberry	Washburn	30 per week*	Y
Thilmany	Beecher	Marinette	30 per week	Y
* Projected to be higher in 2011-2012 with storm damage in Burnett, Douglas, and Washburn Counties.				

3.8 GIS Mapping of Logging Operations Influential Factors

An important objective of this study is determining the sources, haul routes, and destinations of raw forest products in the state. Geographic Information System (GIS) maps are an important tool to illustrate and manage data associated with the flow of logs from forested lands to planned destinations. Data collected from industry resources in the previous sections were applied to standardized GIS map platforms.

To achieve a visual representation of the potential factors that influence logging operations, a GIS map with various layers was constructed to depict the distribution of forest lands, mills, railroad sidings, and the most recent logging routes (spring 2010 and spring 2011) used by truckers to deliver logs to landings, railroad sidings, and processing facilities. The forest lands information was downloaded from the Protected Area Database of the United States (PAD-US 2011). PAD-US is a GIS database hosted by the United States Geological Survey (USGS) Gap Analysis Program, which illustrates and describes public land ownership, management and conservation lands nationally, including voluntarily provided privately protected areas. Mill locations were provided in the form of latitude and longitude coordinates by the Northern Research Station Forest Inventory and Analysis (FIA) unit of the United States Department of Agriculture (USDA) Forest Service. The most recent logging routes were obtained through a survey of GLTPA members and private forest land owners. The base map used was the road network of the state and was supplied by the GIS staff of the WisDOT Northwest Region. This map can assist in identifying the sources of public raw forest products, an important objective of this study.

Figure 3.3 shows the distribution of government owned forest land locations across the state. The bulk of forest land can be found in Northern Wisconsin and thus provide the opportunity for active logging operations in the region.

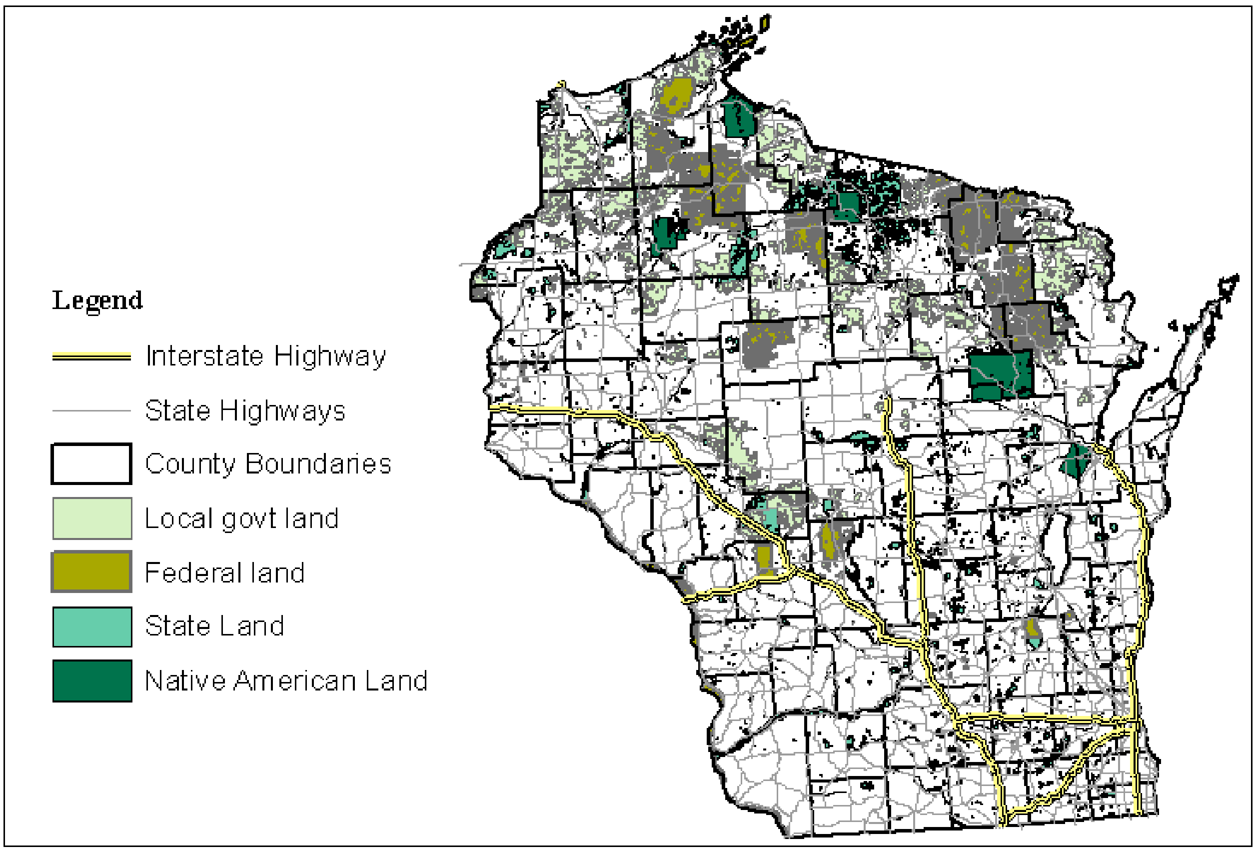


Figure 3.3 Government Forest Lands in Wisconsin

Wisconsin mill types and their corresponding locations are shown in Figure 3.4 with the most recent routes used in transporting logs to various destinations. In addition, the six counties with high roundwood demand are highlighted on the map to show their relationship with the surrounding mills and truck routes. The majority of the pulp mills appear to be within the six high-demand counties. In addition, there is a concentration of veneer mills and railroad loadouts in this region, thus making the region conducive for logging activities.

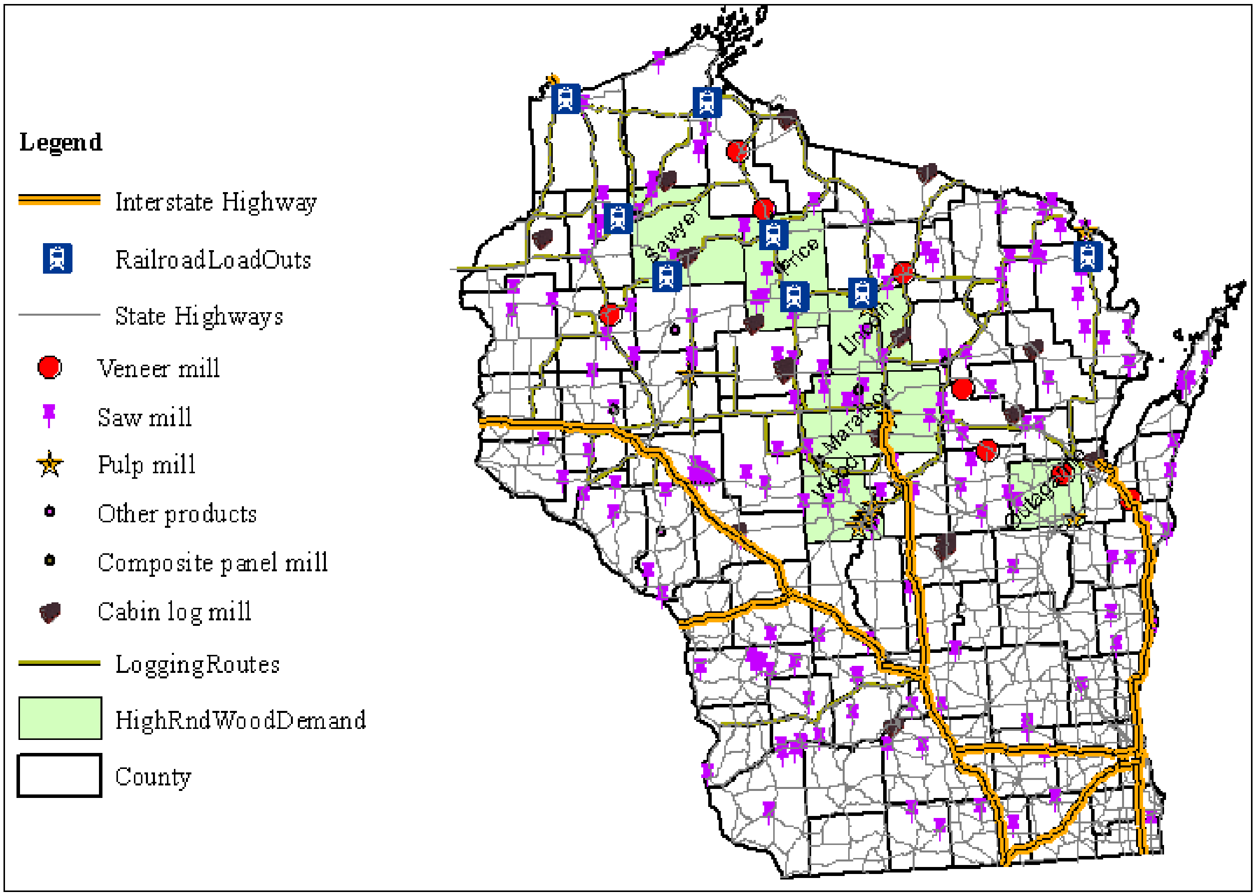


Figure 3.4 Mill Locations in Wisconsin

3.9 Summary

Data were collected from sectors within the logging industry to broaden knowledge and provide a basis for selecting pavement segments for field evaluation. GLTPA members were surveyed to examine how spring load restrictions (SLR) generally impact their operations, short-term impacts on the RS permit law, and the firm size relationship with the average number of logging trips generated per day. Nearly all respondents (95%) change routes during the SLR period and reduce load to comply with regulations. The combination of longer routes and vehicle changes prevent some haulers from hauling during the SLR period.

A comparison between 2010 and 2011 showed not much difference in the total number of average logging trips per day generated between the two time periods, but there was an approximately $0.08/mile higher operating cost per mile for 2011. Average logging trips generated per day from 2010 to 2011 increased from 12.8 to 13.0 trips/day. Average miles traveled during the SLR restriction period also increased between 2010 to 2011 from 23,127 miles to 28,354 miles. Average operating cost also increased from $1.75/mile to $1.83/mile.

Seasonal variations affect where the wood is harvested is Wisconsin. Areas with more cohesive soils allow for more flexibility in the haul routes as the logging companies will have a greater selection of routes to choose from during Spring Thaw. Tree species is an important factor in the determination of destinations and sources for the raw forest products. With 23 commercial types of trees in Wisconsin forests, the logging companies are drawn to the wood necessary for their products. Based on productivity guidelines (Managed Forest Lands regulations), the rotation age for most hardwoods (including Red Pine) is at least 60 years.

Attendance at the 66th annual Logging Congress provided an opportunity to meet industry personnel and obtain information on logging practices. Interviews with attendees found that:

- Pricing at certain mills are a combined $/cord and $/mile, or $/ton.
- Logging season generally begins after the first frost in October when sap begins to run, and ends in March when it becomes difficult to drive in thawing soil.
- Monday through Friday hauling is common, while a few mils operate 24/7. Saturday operations are generally mulch or chips from logging during the weekdays.
- Load limits vary among counties and roadways presenting a challenge for routing logging trucks.
- Landings to temporarily store wood for later hauling or transloading to rail cars are important collection points for local roads with weight restrictions. It is possible to haul anytime of the year from landings, such as during spring thaw, unlike from the woods.
- Border hauling from Wisconsin to Michigan (or back) presents a permit challenge, where hauling from Wisconsin to Michigan requires one plate, and hauling from Michigan to Wisconsin requires two plates. Michigan log haulers generally do not want to travel into Wisconsin with additional restrictions.

The Forestry Division of the Wisconsin DNR provided information regarding public lands designated for logging, as well as the harvest volumes and directional distribution of logs in Wisconsin. The most recent 2008 data indicated that 250 million cubic feet of roundwood was harvested in Wisconsin. Six counties accounted for 73% of the in-take of the roundwood. Wood County received approximately 35% of the total roundwood harvested in Wisconsin, some via rail, while the remaining counties are Lincoln, Marathon, Price, Sawyer, and Outagamie Counties. These counties, or those in close proximity, should naturally be the focus of a field pavement evaluation, and address a key objective of this study by providing a means to identify key destinations/sources of raw forest products.

Destinations of haul trucks were obtained through meetings with four large paper mill companies in the state, as well as a review of literature. The primary destinations of loaded log trucks are pulp, paper, and saw mills within the state and along the Michigan and Minnesota borders. There are a total of 56 pulp and paper mills, and over 300 sawmills in the state. Some rail shipments are sent to Canada, Tennessee, or Virginia. Other destinations include landings and railroad loadout facilities. Identification of these destinations allows WisDOT to understand that the composition of truck loads in the pavement region will likely include logging trucks.

Meetings with pulp and paper mill staff identified those mills that receive (or do not receive) 98,000-lb 6-axle log loads during spring thaw, and whether the scale may be used to collect truck weight and axle weight data. Numerous mills are located in regions with high-end pavement designs, in particular PCC pavements. These locations are primarily in the Chippewa and Fox River Valleys, presenting difficulty in assessing the seasonal effect of 98,000-lb 6-axle trucks. As a result, several mills were removed from consideration for field pavement evaluation.

Railroad sidings and landings provide an important source for log trucks. Meetings with pulp and paper mill companies identified larger landings and railroad sidings used actively for transloading and moving logs towards the mills.

Finally, GIS maps were created using industry data to illustrate and manage data associated with the flow of logs from forested lands to planned destinations. In addition, candidate segment locations within the network of roads to be studied could be visualized on a GIS map.

Chapter 4 – Field Experimental Design

4.1 Introduction

This chapter develops the field experiment for determining whether there is an impact from logging truck permit revisions on pavement condition. The experiment was designed by creating a database of flexible pavements, selecting a sampling approach, presenting candidate highway segments, and selecting and finalizing highway segments for field evaluation.

4.2 Database of Flexible Pavements

A comprehensive database was created for all pavement segments in the state under Wisconsin DOT management for the purpose of selecting appropriate segments for field evaluation. Databases were obtained from the Bureau of Technical Services and Bureau of State Highway Programs for highway geometrics, new construction reports, traffic levels, and performance data. Table 4.1 presents the collected databases with a brief description of key data fields.

Table 4.1 Databases Accessed for the Study

Database (1)	Description (2)
Meta Manager	This database compiles traffic, safety, and roadway data with forecasts of anticipated traffic levels. Data sets from each of the 5 regions were combined into one dataset using the pavement sequence number (SEQNO). Key data fields in this data set were highway number, pavement sequence number, Reference Point (RP), termini of segment, pavement type, functional class, number of lanes, AADT, and percent trucks.
Pavement Information Files (PIF)	Descriptions and pavement distress data for each sequence number (SEQNO) are provided in the PIF database, including International Roughness Index (IRI), Pavement Condition Index (PCI), rutting depth, and individual pavement distress measurements (alligator cracking, edge raveling, etc.). This database also includes highway number, surface year, segment termini description, directional lane of measurement, date of measurement, region number, and county.
New Construction (Ride) Reports	Attributes of projects constructed in a given year are detailed, including such fields as prime contractor, base type and/or preparation (DGBC, OGBC, milled, pulverized, etc.), thickness of asphalt layer placed, lane-miles of paving, and project identification number. Additional detail is provided for *mixture type*, such as Marshall mix designs (HV, MV, and LV), Superpave (ESAL series in millions: E-0.3, E-1, E-3, E-10, E-30, and E-30X), SMA, and Warranty.

The Meta Manager, PIF, and New Construction databases were merged by pavement Sequence Number to yield a single composite database for every pavement segment in Wisconsin. The Sequence Number represents a discrete section of pavement delineated by visible or ordinal beginning and ending termini points, such as intersections, bridges, or section lines. Construction data in electronic form were only available from the year 1989 to present, and unfortunately, no electronic construction records are provided for pavements surfaced before 1989. For pavement constructed before 2000, no Sequence Number is provided in the New Construction Reports, so a merge procedure was developed using the hierarchy of surface year, county number, and highway number. Then, a manual verification was performed to ensure accuracy. The SAS™ software package efficiently performed this merge. These individual segments were then combined to yield a full description with supporting data for each Sequence Number. A total of 9,636 unique asphalt pavement segments (Sequence Numbers) were assembled. Each Sequence Number has about 200 columns of data, with a majority containing extent and severity of individual PCI distresses.

The merged database was then stratified by pavement type: (1) asphalt concrete paved over flexible base known as Type 1, (2) asphalt concrete paved over rigid base known as Type 3, and PCC pavement identified as Type 4, 5, 6, or 8. PCC pavement segments were removed from consideration due to the scope of the study. Of interest were the Type 1 asphalt pavements constructed over flexible base more prone to truck loading effects during the spring thaw period. Type 3 segments were initially retained for comparative purposes during the segment selection process but later removed. Both rural and urban sections were retained, however, rural sections were favored to remove the effects of slower vehicle speeds and unbalanced loading cycles (e.g., intersections), along with different surface drainage configurations. All asphalt mixture design types were retained for selection, including Recycle #6 (pre-HV/MV/LV series), Marshall mix designs (High Volume, Medium Volume, Low Volume), SMA, and Superpave (ESAL series).

4.3 Pavement Selection

Selection of pavement segments for field evaluation aligned the data and information presented in prior sections of the report with the study objectives. Several important criteria during this selection were:

- Highways where 98,000-lb log trucks were operated during the spring thaw.
- Known destination(s) of the loaded log trucks.
- Known direction of loaded and empty log trucks on a given highway.
- Two-lane highways to channel truck traffic to a single directional lane.
- Proximity of a weigh scale to measure truck weight and per-axle weight.
- Cooperation by the weigh scale operator to collect data, recognizing the fact that the log hauler is typically a contractor independent of the weigh scale operator.
- Asphalt pavement; preferably in a cluster to increase the amount of collected data.
- Pavement base must be flexible, not rigid (PCC).
- Emphasis on northern logging regions of the state.

- Multiple destinations (mills, landings, and railroad loadouts) in a concentrated area that can enhance the data set for a given level of effort.
- A range of pavement structures, ages, conditions, and traffic can broaden the evaluation and address a key study objective if certain pavements are impacted with increased loads due to policy change.
- Proximity of the sections to forests damaged by a line of severe thunderstorms on July 1, 2011 that moved through Pine County, Minnesota, and northwestern Wisconsin counties of Burnett, Washburn, and Douglas. Pavements in the vicinity of these counties would be expected to experience a higher level of log truck traffic during the field evaluation.

.

4.4 Sampling Approach

Two primary pavement sampling approaches were evaluated: (1) an independent sampling methodology that compares logging and non-logging pavement regions, and (2) a split sampling approach that compares opposing lanes of pavements used for logging routes. Each of these approaches has direct statistical implications.

Independent sampling collects data from two distinct data sets for a comparison. In this scenario, pavement distress data are compared among a group of logging routes and non-logging routes to determine if there is difference in pavement performance. The advantage of this approach is sampling whether logging and non-logging pavements are performing equally, differently, or the same across a range of pavement designs and traffic levels. The disadvantage of independent sampling is introducing more variability into the data set and overall analysis, potentially obscuring whether a difference exists in pavement performance with the new RS Permit. Discerning factors in pavement deterioration may be confounded. For example, there are several variability sources introduced with the log/non-log pavement comparison such as soil type, soil support value, pavement base type, asphalt layer thickness, structural coefficients and structural number, asphalt resilient and dynamic modulus, pavement age, AADT, percent trucks, maintenance treatments, and environmental factors (precipitation, temperature range).

The introduction of independent sampling variability specific to logging routes is expressed by Eq. 4.1.

$$2\sigma^2_{\text{Log, Non-Log}} = \text{Var}\,(X_{\text{Log}} - X_{\text{Non-Log}})$$
$$= \text{Var}\,X_{\text{Log}} + \text{Var}\,X_{\text{Non-Log}} \quad \text{(assuming equal variances)} \qquad (4.1)$$

Where,

$\sigma^2_{\text{Log, Non-Log}}$ = independent sample variability of pavement deterioration at logging and non-logging pavements;
Var = Variance;
X_{Log} = Logging Route pavement performance (PCI, IRI, rutting, etc.); and
$X_{\text{Non-Log}}$ = Non-Logging Route pavement performance (PCI, IRI, rutting, etc.).

Split sampling collects data from one data set where there are specific treatments applied to a split of a feature of interest. Under this scenario, for a given highway segment, a comparison is made between pavement performance from opposing lanes of traffic where loaded and unloaded log trucks travel. This sampling approach has a distinct advantage of blocking all of the previously cited variability sources. The disadvantage is requiring a lesser number of pavement segments in the comparison as in the independent sampling approach; however, with limited and valuable funds, this shortcoming is outweighed by statistical efficiency. The split-sample design simply removes the variability associated with different soil types, pavement types, AADT, etc., and has less variability than the independent sampling design. The only variability introduced with this approach is from sampling and testing, where the specific sampling location may vary, as well as the measurement technique and operator. However, the same sampling and testing variability sources are also found in independent sampling.

The variance produced with a split sampling approach as it pertains to a logging route comparison is described by Eq. 4.2:

$$\sigma^2_{\text{bi-directional loaded vs. empty}} = \text{Var}(X_L - X_E) = \text{Var}X_L + \text{Var}X_E - 2\text{Cov}(X_L, X_E) \qquad (4.2)$$

Where,

$\sigma^2_{\text{bi-directional loaded vs. empty}}$ = split sample variability of pavement deterioration at given segment;

Var = Variance;

Cov = Covariance;

X_L = Loaded Lane pavement performance (PCI, IRI, rutting); and

X_E = Empty Lane pavement performance (PCI, IRI, rutting).

Information collected from the initial tasks in this study allowed the more statistically-efficient split sampling approach to be chosen since there was a fundamental understanding of the sources and destinations of logging loads. Knowledge of the log sources, haul routes, and destinations from industry meetings and the support of GLTPA, while considering the statistical implications of the sampling design, determined that data collected from logging-only routes would better meet the study objectives. The recommended approach uses direction of loaded and empty logging trucks during spring thaw - on the same stretch of highway - to determine whether there is an impact on the pavement.

4.5 Candidate Highways

A list of all candidate destinations was created using the enumerated criteria and recommended bi-directional sampling approach. Important information collected during the initial phase of the study are knowledge of loaded and empty log truck direction, weigh scales available for research purposes, and two-lane asphalt pavements with flexible base. Table 4.2 presents seven candidate destinations for preliminary pavement selection. The first four destinations meet nearly all primary criteria described earlier. Destinations that have potential issues with sampling are the Tomahawk area with high-end 4-lane asphalt pavement on USH 51, the Pembine/Beecher railroad sidings with bi-directional loaded traffic on USH 141, and the Wausau area mills with primarily PCC pavements and high-end 4-lane asphalt pavement on USH 51 and Business USH 51.

Table 4.2 Destinations of 98,000-lb Log Trucks during Spring Thaw

Index (1)	Destination(s) (2)	City(s) (3)	County(s) (4)	Type 1 Asphalt Pavements in Vicinity of Destination (loaded direction) (5)	Estimated Truck Frequency during Spring Thaw (6)
1	Flambeau River Papers paper mill; NewPage railroad siding	Park Falls; Fifield	Price	STH 13 n. of Park Falls (sb) STH 13 s. of Park Falls (nb) STH 182 e. of Park Falls (wb) STH 70 w. of Fifield (eb) STH 70 e. of Fifield (eb) CTH E w. of Park Falls (eb)	30 per week
2	Thilmany railroad siding; Louisiana-Pacific sawmill	Stanberry; Hayward	Washburn Sawyer	STH 77 w. of Hayward (eb) STH 77 e of Hayward (wb) STH 27 n. of Hayward (sb) STH 27 s. of Hayward (nb) USH 63 is concrete	30 per week
3	Domtar railroad siding; NewPage railroad siding	Exeland, Weirgor; Ladysmith	Sawyer Rusk	STH 48 w. of Exeland (eb) STH 40 n. of Exeland (sb) STH 40 s. of Exeland (nb) STH 70 w. of Radisson (eb) STH 27 n. of Ladysmith (sb)	60 per week
4	Domtar pulp & paper mill; NewPage pulp & paper mill	Nekoosa; Wis. Rapids	Wood	STH 34 n. of Wis Rapids (sb) STH 13/34 Wis Rapids is PCC STH 13 w. of Wis Rapids is PCC STH 54 w. of Port Edwards (eb) STH 173 w. of Nekoosa (eb) STH 73 e. of Nekoosa (wb) STH 13 s. of STH 73 (nb) CTH Z s. of STH 73 (nb)	200 per week
5	PCA paper mill; Louisiana-Pacific paper mill	Tomahawk	Lincoln	USH 8 w. of Bradley (eb) USH 8 e. of USH 51 (wb) USH 51 n. of STH 86 (sb) STH 86 w. of Tomahawk (eb) STH 107 s. of Tomahawk (nb)	30 per week
6	NewPage railroad siding; Thilmany railroad siding; Verso pulp & paper mill (Michigan)	Pembine; Beecher	Marinette	USH 141 n. of Pembine (sb & nb) USH 8 w. of Pembine (eb) USH 141 s. of Pembine (sb & nb)	150 per week
7	Domtar pulp and paper mill	Rothschild	Marathon	USH 151 n. of Wausau (sb) STH 52 e. of Wausau (wb) STH 29 PCC IH 39 PCC (80k limit)	20 per week

Features associated with the seven destinations are shown in Tables 4.3 and 4.4. Table 4.3 lists the four primary destinations meeting most criteria, while Table 4.4 has other destinations that marginally meet the criteria. Features are divided into categories for location, description, construction, age, traffic, and performance.

Table 4.3 Primary Candidate Pavement Segments for Field Evaluation

Location	Description			Construction				Age	Traffic		Performance		
	Highway	County	General Location	Base	Thickness (in.)	Mix Type	Pavement Type		AADT	Truck %	IRI	Rutting	PCI
1 (Fifield/ Park Falls)	13	Price	Park Falls-North Co. Line	Old PCC	Concrete								
	13	Price	Fifield-Park Falls	Old AC	1.75	E-3	1	4	4810	12.9	74	5	85
	70	Price	West Co. Line - STH 13	Pulverize	4	E-1	1	6	590	13.0	50	4	97
	182	Price	STH 13 - Saunders Ave, City of Park Falls	Crack & Seat	5.25	E-3	1	10	5120	6.3	133	11	70
	182	Price	Saunders Ave - Iron Co. Line	New Base	3.6	LV	1	12	550	13.0	85	18	60
2 (Stanberry)	27	Sawyer	STH 70 - Hayward	Pulverize	4.5	E-1	1	7	3570	8.5	51	10	96
	77	Washburn	CTH M - STH 27	Dense Grade	4.5	MV	1	11	1680	13.0	71	36	65
3 (Exeland/Wiergor/ Ladysmith)	8	Rusk	Ladysmith - Glen Flora	Old AC	3.5	MV	1	15	N/A	N/A	N/A	N/A	N/A
	27	Rusk	South Co. Line - Ladysmtih	Old PCC	Concrete								
	27	Rusk	Ladysmith - Brunet Bridge	Old AC	4.0	E-1	1	6	3140	8.2	46	11	94
	27	Rusk	Ladysmith - Ojibwa	Old AC	5.0	E-1	3	21	4190	7.1	184	31	60
	40	Rusk	Becky Creek - North Co. Line	Old AC	4.0	E-0.3	1	6	710	11.6	82	20	88
	48	Sawyer	CTH C - STH 40	Dense Grade	4.0	LV	1	16	N/A	N/A	109	28	66
	70	Sawyer	CTH B - CTH GG	Dense Grade	4.0	MV	1	11	1330	13.0	65	11	94
4 (Wisconsin Rapids/ Nekoosa)	13	Wood	CTH D - Hasa Ln	Old AC	5.5	E-3	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	13	Wood	Keisling Rd - STH 73	Old AC	3.5	E-3	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	34	Portage	Rudolph - USH 10	Old AC	3.0	MV	1	11	3040	18.4	91	17	74
	54	Wood	Swanson Rd -Seneca Rd	Dense Grade	3.5	E-3	1	6	2720	9.0	50	8	93
	54	Wood	2nd Ave South, Wisconsin Rapid	Dense Grade	4.0	E-3	1	7	10240	7.6	N/A	7	82
	54	Wood	CTH G - Swanson Rd	Dense Grade	5.0	MV	1	13	3670	16.1	79	15	93
	73	Wood	CTH U -STH 13	Old AC	3.0	E-3	1	2	2100	10.8	45	14	100
	73	Wood	STH 13 -Clark Co. Line	Old AC	4.0	E-1	1	2	1910	11.6	41	23	100
	73	Wood	Nekoosa - Port Edwards	Rubblize	4.0	E-3	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	73	Wood	STH 13 -Nekoosa	Old AC	5.0	E-3	3	7	6880	5.3	91	8	86
	173	Wood	Wood Ave, Nekoosa	Pulverize	4.0	E-3	1	5	2390	4.6	N/A	20	100

Table 4.4 Other Candidate Pavement Segments for Field Evaluation

Location	Description			Construction				Age	Traffic		Performance		
	Highway	County	General Location	Base	Thickness (in.)	Mix Type	Pavement Type		AADT	Truck %	IRI Average	Rutting	PCI
5 (Tomahawk)	8	Lincoln	McCord Rd - North County Line	Old AC	2.5	E-3	3	10	3100	20.6	65	11	69
	51	Lincoln	CTH S - USH 8,SB	Rubblize	7.5	E-10	1	5	12760	20.6	65	4	96
	86	Lincoln	Spirit Rv. to Tomahawk	Dense Grade	5.0	Recycle	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	86	Lincoln	Spirit-Tomahawk	Dense Grade	1.75	E-3	1	6	790	8.5	72	5	91
	107	Lincoln	Merrill-Tomahawk	Old AC	1.75	E-3	1	6	1740	5.1	79	5	89
6 (Pembine/ Beecher)	8	Marinette	USH 141-Michigan State Line	Old AC	2.5	E-1	1	1	2520	10.6	55	15	100
	8	Marinette	CTH R - North JCT USH 141	Rubblize	6.5	E-3	1	2	4890	7.4	43	N/A	100
	141	Marinette	Beecher-Pembine	Old AC	3.5	E-3	1	7	6390	7.4	40	6	81
	141	Marinette	Wausaukee-Amberg	Old AC	4.0	E-3	3	5	7670	7.4	82	5	63
7 (Wausau)	39	Marathon	Maple Ridge Rd - BUS 51	Rubblize	8.25	E-10	1	1	22220	13.9	33	7	100
	39	Marathon	Wausau - CTH U	Old PCC	Concrete								
	39	Marathon	STH 29 - STH 34	Old PCC	Concrete								
	51	Marathon	CTH WW-Silver Creek	Old AC	2.0	E-10	1	1	20130	13.5	52	4	100
	52	Marathon	Wausau -Shawano Co. Ln	Old AC	3.5	E-1	3	7	2670	9.2	91	N/A	78
	107	Marathon	CTH A-Lincoln Co. Ln	Old AC	3.5	E-1	1	4	4300	4.1	121	7	100
	B51	Marathon	Merrill Ave, Wausau	Dense Grade	5.0	E-3	N/A	N/A	N/A	N/A	N/A	N/A	N/A

The primary asphaltic highway segments for shipping logs are shown as green color in Figure 4.1 and are concentrated in Sawyer, Price, and Wood Counties. Additional counties that are destinations for raw forest products are Lincoln, Marathon, and Outagamie Counites. In all, these six counties account for 73 % of all log intake in the state and are shaded blue. Naturally, the study focused on these six counties and neighboring counties.

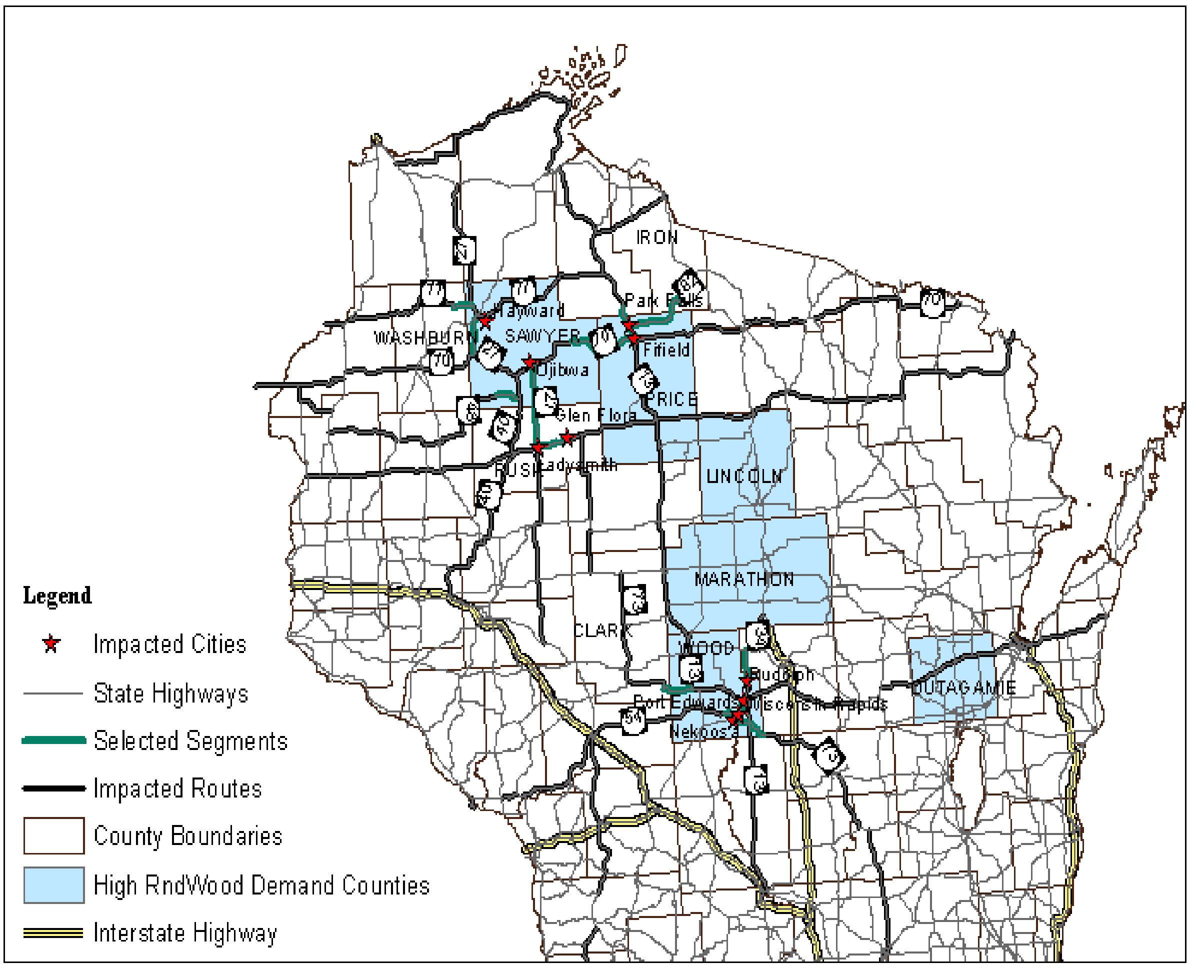


Figure 4.1 Segment Locations for Field Data Collection

4.6 Highway Selection

The selection and recommendation of highways for field evaluation was narrowed to four log destinations: (1) Park Falls and Fifield area, (2) Stanberry and Hayward area, (3) Exeland and Ladysmith area, and (4) Nekoosa and Wisconsin Rapids area. Three additional destinations that had potential for data collection but with sampling concerns were (1) Tomahawk with high-end 4-lane asphalt pavement on USH 51, although STH 86 west of Tomahawk is attractive for loads to the PCA mill, (2) Pembine and Beecher railroad sidings with bi-directional traffic on USH 141 (in conflict with the split-sampling approach), and (3) Wausau-Rothschild area mills with primarily PCC pavements and high-end 4-lane asphalt pavement on USH 51 and USH Business 51.

Final selection of pavement segments was based upon the important criteria enumerated earlier (highways operating 98,000-lb truck weights during the spring thaw, cooperation of weigh scale operators, proximity to July 2011 damaged forests, etc.), as well as the study budget. With a goal to collect as much quality data within the budget as possible, two adjoining clusters were selected: (1) Stanberry and Hayward area (named Hayward cluster), and (2) Exeland and Ladysmith area (named Radisson cluster). Additional resources would have been necessary to concurrently collect data from the Park Falls and Fifield area, and at the Nekoosa and Wisconsin Rapids area. These two areas would have also provided quality data, but data collection was not feasible given the study budget.

The selected highways for data collection in the Hayward and Radisson clusters are listed in Table 4.5 The termini for each highway segment is defined by the construction limits when the pavement was constructed. In all, there were 11 specific highway segments evaluated, with number of Sequence Numbers within each segment varying from one (STH 77 Minong) to four (STH 40). Chapter 5 describes how data were collected on each of these highway segments.

Table 4.5 Highway Segments chosen for Data Collection

Index	Highway Number	County	Project Limits	Surface Age, years	Surface Thick-ness, inches	Base	Asphalt Mix	Sequence Numbers
1	77	Burnett	STH 35 Int. to East County Line	1	5	Dense CABC	Warranty E-1	96390 96400 96410
2	77	Washburn	West County Line to Minong	7	5	Dense CABC	Standard E-1	96430 96460 96480
3	77	Washburn	County I to USH 53 Minong	13	5	Dense CABC	Marshall MV-2	96540
4	77	Washburn	Minong to CTH M	12	4.5	Dense CABC	Marshall MV-2	96600 96630 96660
5	27	Sawyer	STH70 to Hayward	8	4.5	Pulverize	Warranty E-1	32780 32810 32820
6	27/70	Sawyer	STH40 to CTH C	2	2	Existing Asphalt	Warranty	32600 32610 32620
7	27/70	Sawyer	Radisson to Ojibwa	13	4	Existing Asphalt	Marshall MV-2	32550 32560 32570
8	27	Sawyer	Ladysmith to Ojibwa	7	4	Existing Asphalt	Standard E-1	32350 32360 32370
9	48	Sawyer	West County Line to STH 40/CTH D	1	3	Milled Asphalt	Warranty E-3	65330 65340 65350
10	40	Rusk	Becky Creek to North County Line	1	1.75	Existing Asphalt	Warranty E-3	50820 50830 50840 50850
11	40	Sawyer	STH 48 to STH 27/70 Radisson	19	4.0	Dense CABC	Marshall LV-1	50880 50910 50920

4.7 Summary

This chapter developed the field experiment to determine whether there is an impact from logging truck permit revisions on pavement life. The experiment created a database of flexible pavements, selected a sampling approach, considered several candidate highway segments, and finally selected highway segments for field evaluation.

A comprehensive database was created for all pavement segments in the state under Wisconsin DOT management for the purpose of selecting appropriate segments for field evaluation. A total of 9,636 unique asphalt pavement segments (Sequence Numbers) were assembled.

Two primary pavement sampling approaches were evaluated: (1) an independent sampling methodology that compares logging and non-logging region pavements, and (2) a split sampling approach that compares opposing lanes of pavements used for logging routes. Knowledge of the log sources, haul routes, and destinations from industry meetings and the support of GLTPA, while considering the statistical implications of the sampling design, determined that data collected from logging-only routes would better meet the study objectives. The recommended split-sampling approach uses direction of loaded and empty logging trucks during spring thaw on the same stretch of highway to determine whether there is an impact on the pavement.

Selection of pavement segments for field evaluation considered several important criteria: (1) highways operating 98,000-lb log truck weights during the spring thaw; (2) known direction of loaded and empty log trucks on a given highway; (3) multi-lane highways to channel truck traffic to a single directional lane; (4) cooperation by the weigh scale operator to collect data; (5) asphalt pavement preferably in a cluster to increase the amount of collected data; (6) emphasis on northern logging regions of the state; (7) a range of pavement structure, age, condition, and traffic; and (8) proximity of the sections to forests damaged by a line of severe thunderstorms July 2011 that moved through northwestern Wisconsin counties of Burnett, Washburn, and Douglas.

Two adjoining highway clusters were selected, including the Hayward cluster and Radisson cluster. A total of 11 specific highway segments were selected, with the number of Sequence Numbers within each segment varying from one (STH 77 Minong) to four (STH 40 northern Rusk County).

Chapter 5 – Data Collection

5.1 Introduction

This chapter describes field data collection in the vicinity of two logging truck clusters of Hayward and Radisson. Monthly activities included traffic counts, log truck weight data, and pavement condition measurements. Traffic and distress data were collected at the two highway clusters on a monthly basis from December 2011 through May 2012, as shown in Table 5.1. Additionally, Wisconsin DOT performed IRI and rut measurements of the chosen highway segments in October 2011 (before the Frozen Road Declaration) and in May 2012 (after the Spring Thaw Suspension Period). Logging truck weight data were collected from electronic records continuously during the evaluation period. The following sections detail the field data collection activities and present a preliminary summary of the collected data.

Table 5.1 Monthly Traffic and Distress Data Collection

Monthly Evaluation (1)	Dates (2)
1	December 19-23, 2011
2	January 9-13, 2012
3	February 13-17, 2012
4	March 19-23, 2012
5	April 16-20, 2012
6	May 14-18, 2012

5.2 Traffic Data

At least three Sequence Numbers within each highway segment were selected for performance evaluation to strengthen the sample size and provide an estimate of sampling and testing variability. A single Sequence Number within each highway segment was identified for traffic counts. Within each of the two clusters, a control segment was selected for a Monday through Friday traffic count, as meetings with industry revealed that most hauling operations occur during the weekday and during business hours. There is a lesser amount of hauling on Saturdays, thus, no data collection occurred for Saturday. The 24-hour volume counts were collected on the other highway segments, known as *coverage* stations, which exhibit traffic patterns similar to the established *control* count highway. The control and coverage count station concept is illustrated in Figure 5.1.

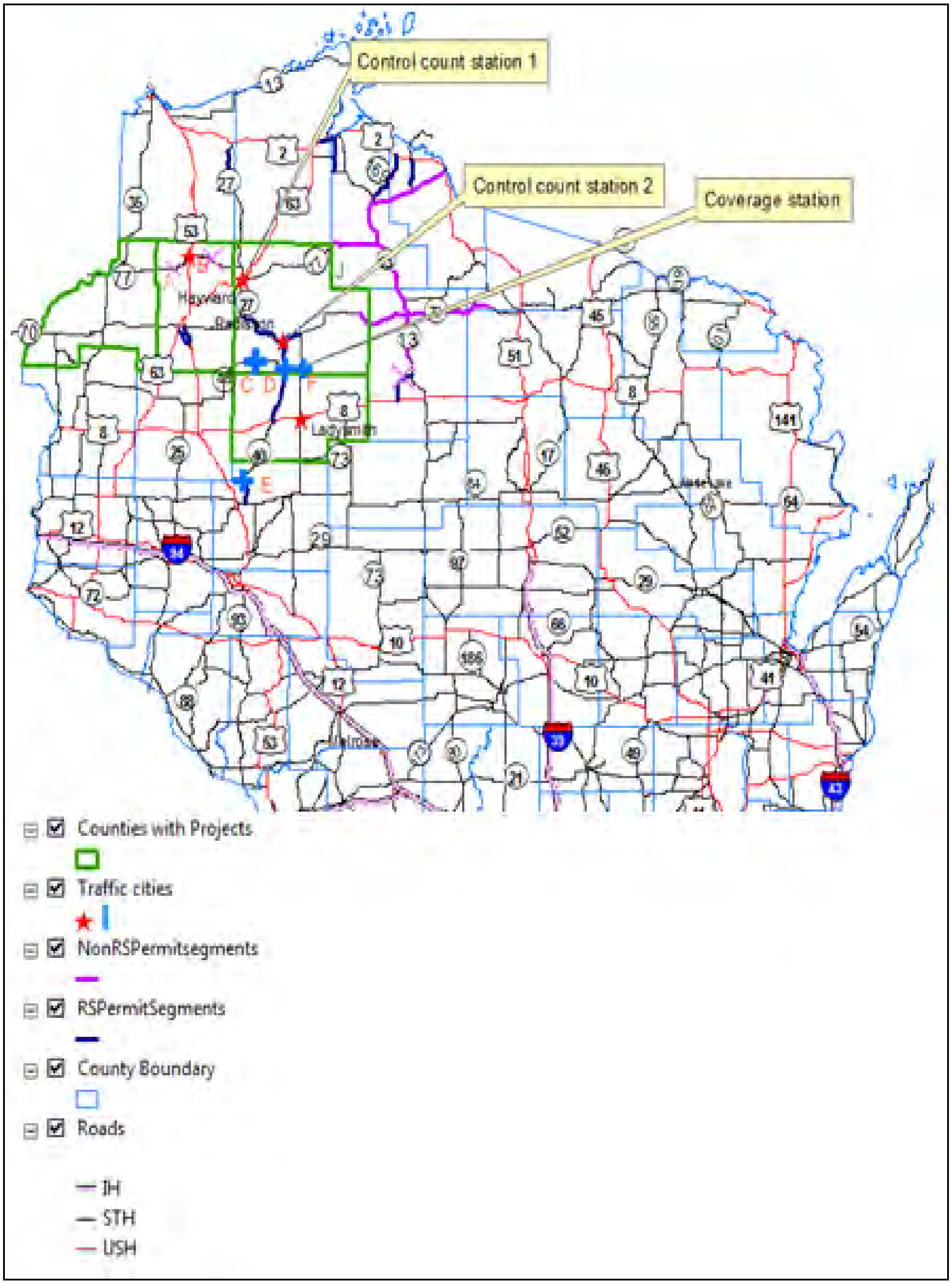


Figure 5.1 Illustration of Control and Coverage Count

In Figure 5.1, control count station #1 at Hayward and surrounding coverage stations A and B were established for a set of highways for destination #1. Control count station #2 at Radisson and coverage stations C through F are established for highways in the vicinity of destination #2. The counting schedule for a given week in any month is shown in Table 5.2. Two counters remained at the control stations during the entire 5-weekday period of count in a given month, while the other counters were moved daily. Trax Flex HS™ automatic traffic data recorders captured bi-directional traffic data on the highway segments. The recorders obtained vehicle classification counts and corresponding observation times in both highway directions. To distinguish between logging trucks (loaded or empty) and all other trucks, visual sampling counts were performed daily at each control station in the morning and afternoon and for one day at each coverage station. This important visual data was used in conjunction with volume data from the automatic traffic recorder to estimate the expected logging truck volume for each segment.

Table 5.2 Weekly Count Schedule for Sample Network

Station **(1)**	**Day of count** **(2)**
Control 1, Hayward	Monday-Friday
Control 2, Radisson	Monday-Friday
Coverage A	Monday
Coverage B,C	Tuesday
Coverage D	Wednesday
Coverage E	Thursday
Coverage F	Friday

There was near certainty that snowplowing operations would temporarily force removal of the traffic counter tubes from the pavement; therefore, two radar recorders were purchased and mounted at control count stations to ensure continuous traffic measurement. A shortcoming of the radar is that it records only volume and vehicle length but not axle configuration. Data were correlated between the Trax Flex HS™ automatic traffic data recorders and the radar recorders using observation time, vehicle class measurement lengths, and raw lengths. The radar recorder was positioned adjacent to the control station road tubes. Figures 5.2 and 5.3 illustrate the traffic counters at Hayward and Radisson, respectively, using parallel road tubes to collect direction and axle configuration of each vehicle.

Figure 5.2 Hayward traffic counter on STH 27

(a) Road tubes for bi-directional traffic **(b) Radar recorder adjacent to road tubes**

Figure 5.3 Radisson traffic counter on STH 27/70

5.3 Performance Data

Two primary types of pavement performance data were collected: (1) manual measurements recorded monthly for each highway segment, and (2) semi-automated measurements by Wisconsin DOT Pavement Data Unit. Both the manual and semi-automated measurements were recorded prior to the Frozen Road Declaration and after the Spring Thaw Suspension Period. In addition, the manual measurements were recorded monthly between these key periods during early 2012.

Manual pavement performance measurements were recorded for three Sequence Numbers within each highway segment once each month. Within each Sequence Number, a 500-foot test section in opposing lanes was identified for field distress measurements. Typically, Wisconsin DOT specifies a 528-foot test segment at 0.3 to 0.4 miles from the beginning of the Sequence Number reference point with adjustments allowed for bridges, railroad crossings, or other anomalies. In this study, distance from the start of the reference point to start of the test section varied primarily for safety reasons so that there was adequate sight distance between a vehicle and the field survey crew. All test segments were in 55 mph posted speed zones. In most cases, the test section was on a tangent section away from vertical curves offering maximum driver sight distance to the field survey crew.

Three specific load-related distresses were rated in the right and left wheel paths of each test section including:

(1) Longitudinal cracking,
(2) Alligator cracking, and
(3) Rutting.

All field distress measurements followed Wisconsin DOT procedures, specifically ASTM D6433-07 (2009), *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys,* and ASTM E1703M–95 (2000), *Standard Test Method for Measuring Rut-Depth of Pavement Surfaces Using a Straightedge*. Figure 5.4 illustrates rutting and cracking measurements. Length of longitudinal cracking and area of alligator cracking were recorded with a measuring wheel. Depth of rutting was measured with a 6-foot straight edge per ASTM requirements. All measurements were recorded in 100-foot increments to effectively manage data collection under live traffic conditions. Cracking length and area were summed for the five 100-foot increments to create a total for the 500-foot test section. Five rutting measurements, one collected every 100 feet, were averaged separately for the left and right wheel paths. Identical distress measurements were collected in the opposing lanes of traffic immediately across the centerline from each other, adhering to the split sampling design recommended earlier.

(a) Rutting measurement **(b) Cracking measurement**

Figure 5.4 Manual Pavement Distress Measurement

The Pavement Data Unit of Wisconsin DOT collected semi-automated performance data in October 2011, May 2012, and October 2012 by measuring the International Roughness Index (IRI) and rut depth using standardized laser-optic methods. Measurements were scheduled on the selected highway segments before the Frozen Road Declaration and after the Spring Thaw Suspension Period. IRI and rut measurements were collected in both directions of the highway segments. An error with the highway segment listing delayed measurement of STH 27/70 (Radisson to Ojibway) and STH 40 (STH 48/CTH D to Radisson) segments until October 2012. Thus, performance data include the effects of summer and fall 2012 vehicle travel on these segments. Figure 5.5 shows semi-automated IRI and rut measurements on STH 40 from the Sawyer/Rusk County Line to Bruce in May 2012.

Figure 5.5 Wisconsin DOT Pavement Distress Measurement on STH 40

5.4 Truck Weight Data

Log truck weight data were collected from platform scales at the entry to log destinations in the vicinity of Hayward and Radisson. Two primary types of data were collected including: (1) individual truck axle weight and axle spacing, and (2) monthly log truck reports from scale operators. The following subsections present an overview of these data.

5.4.1 Truck Axle Weight and Spacing

Individual axle weight and axle spacing data were collected monthly for a period of several hours at two weigh scales. The purpose of collecting this data was to measure and report the actual axle load distribution for various truck axle configurations.

With the cooperation of the scale operators and truck drivers, individual axle weights were measured using calibrated platform scales. Cumulative axle weights were recorded as successive axles occupied the platform scale, then a back-calculation procedure determined the individual axle weights. The truck driver was requested to participate in the measurements, then instructed to stop the truck after each axle rolled onto the scale to allow the scale to stabilize. After the entire truck was stopped on the scale, the distance between axles was recorded. Figure 5.6 illustrates axle weight and axle spacing measurements.

Figure 5.6 Truck Axle Weight and Spacing Measurement

5.4.2 Monthly Log Truck Reports

Operators of the scales provided monthly weight reports for all log trucks that entered and exited the wood yard. Data from the monthly reports included Gross Vehicle Weight (GVW), Empty or Net Vehicle Weight (EVW or NVW), log payload weight, and arrival and departure time. These reports are generated electronically at some scales, while others use paper ticket format and manual data entry. Only electronic data were collected. A mix of 5-axle and 6-axle trucks was recorded at the scales.

Chapter 6 – Traffic Data Analysis

6.1 Introduction

This chapter addresses the measurement and analysis of traffic data and logging truck weight data. An analysis of the traffic data is presented to determine the distribution of vehicle classes and categories. First, the traffic counts from the 11 highway segments are summarized, and then the weights of logging trucks traversing these segments are reported using basic summary statistics.

6.2 Traffic Counts

A primary objective of obtaining traffic counts was to estimate the volume by truck classification of loaded and empty logging trucks in order to determine truck class impact on pavement deterioration. The observed traffic characteristics for the studied road network are described in the following sections.

6.2.1 STH 27 at Hayward

The traffic count location on STH 27 was established just north of Carol Drive in the city of Hayward, Sawyer County (see Figure 6.1) to capture traffic that traveled along the project segment between STH 70 and Hayward. This count location was designated as a control station where traffic counts were conducted for five continuous weekdays once every month from December 2011 to May 2012 using Trax Flex HS™ automatic traffic data recorders. There was near certainty that snowplowing operations would temporarily force removal of the traffic counter and road tubes from the pavement; therefore, a radar recorder was mounted at this station to ensure continuous traffic measurement. A shortcoming of the radar is that it records only volume and vehicle length but not axle configuration. This shortcoming required some correlation of the Trax Flex HS™ automatic traffic data recorders and the radar using observation time, vehicle class measurement lengths, and raw lengths.

Figure 6.1 STH 27 Control Count Station Location in Hayward, WI

Automatic traffic data recorders do not have the ability to distinguish between trucks carrying logs and all other trucks. Initial observations suggested that logging truck movements were scattered throughout the day from approximately 5AM to 5PM. Hence, sample visual counts of logging trucks (loaded or empty) were taken during specific times of the day. Time-of-day adjustments were then used to expand the short-term counts to daily logging truck counts. Time-of-day adjustment tables were derived from the 24-hr volume counts from the automatic traffic recorders.

Table 6.1 shows an adjustment table example for FHWA truck class 9 volume data collected on December 19, 2011 along STH 27 at Hayward. The last column provides the basis for calculating an adjustment factor needed for the expansion of any short-term visual counts for a given observation interval. On this particular day, visual counts were conducted from 6AM through 9AM and the total number of loaded class 9 logging trucks observed northbound was three.

Table 6.1 Adjustment Table Example for FHWA Class 9 Truck derived from Hayward Control Station

Date	Time	FHWA Class 9 Volume by Hour	Hourly % of FHWA Class 9 in total volume
12/19/2011	12:00 AM	0	0
12/19/2011	01:00 AM	0	0.0
12/19/2011	02:00 AM	0	0.0
12/19/2011	03:00 AM	0	0.0
12/19/2011	04:00 AM	0	0.0
12/19/2011	05:00 AM	1	5.6
12/19/2011	06:00 AM	0	0.0
12/19/2011	07:00 AM	2	11.1
12/19/2011	08:00 AM	1	5.6
12/19/2011	09:00 AM	4	22.2
12/19/2011	10:00 AM	3	16.7
12/19/2011	11:00 AM	2	11.1
12/19/2011	12:00 PM	3	16.7
12/19/2011	01:00 PM	1	5.6
12/19/2011	02:00 PM	0	0.0
12/19/2011	03:00 PM	1	5.6
12/19/2011	04:00 PM	0	0.0
12/19/2011	05:00 PM	0	0.0
12/19/2011	06:00 PM	0	0.0
12/19/2011	07:00 PM	0	0.0
12/19/2011	08:00 PM	0	0.0
12/19/2011	09:00 PM	0	0.0
12/19/2011	10:00 PM	0	0.0
12/19/2011	11:00 PM	0	0.0
	total	18	100.0

38.9 (adjustment factor) — 06:00 AM to 09:00 AM

From Table 6.1, the percentages corresponding to the observation interval were added together; this represented 38.9% of the daily northbound loaded class 9 logging truck volume. The daily total northbound class 9 truck volume was estimated using Equation 6.1.

$$V_{\lg ij} = \frac{STV_{ij}}{p} * 100 \qquad (6.1)$$

Where,

V_{lgij} = Daily volume of logging truck class i for direction j;

STV_{ij} = short-term count for logging truck class i for direction j; and

p = percent of truck class i counted during the observation interval.

Applying equation 6.1, the daily class 9 northbound loaded logging truck volume was calculated as, 3 x 100/38.9 = 7.7 → 8. The calculation was repeated for each day for all truck classes for all months.

6.2.1.1 *Conversion of STH 27 Daily Logging Truck Volumes to AADTT*

The American Association of State Highway and Transportation Officials (AASHTO) proposed Equation 6.2 for average annual daily traffic (AADT) estimation and indicated that the use of the formula removes most biases that result from missing days of data, especially when those missing days are unequally distributed across months or days of the week.

$$AADT = \frac{1}{7}\sum_{i=1}^{7}\left[\frac{1}{12}\sum_{j=1}^{12}\left(\frac{1}{n}\sum_{k=1}^{n} VOL_{ijk}\right)\right] \quad (6.2)$$

Where,

VOL = daily traffic for day k, of day-of-week i, and month j;
i = day of week;
j = month of year;
k = 1, when the day is the first occurrence of that day of the week in a month,
k = 4 when it is the fourth day of the week; and
n = the number of days of that day of the week during that month (usually between 1 and 5, depending on the number of missing data).

The above equation suggests that traffic volume data need to be collected for each month of the year, which was not feasible for this study. An alternative approach for estimating AADT suggested by Roess et al. (2011) involves the use of monthly seasonal and daily adjustment factors. The estimate is based on equation 6.3.

$$AADT=V_{24ij}*DF_i*MF_j \quad (6.3)$$

Where,

AADT = average annual daily traffic, vehs/day
V_{24ij} = 24-hr Volume for day i in month j, vehs
DF_i = daily adjustment factor for day i
MF_j = monthly or seasonal adjustment factor for month j.

The Wisconsin DOT maintains more than 200 permanent, continuous data collection stations or automated traffic recorders (ATRs) on Wisconsin's roadways. Wisconsin DOT collects ATR data and produces several reports that include daily, weekly and yearly counts, as well as monthly seasonal adjustment factors and day-of-week factors for various seasonal groups (WisDOT 2011g). The most recent published daily and seasonal data corresponding to 2010 were used in this study for all average annual daily truck traffic (AADTT) estimates. For the STH 27 control station in Hayward, seasonal and daily adjustment factors for the nearest continuous count station were used. The station is located on USH 63 approximately 0.9 mi north of STH 77 in Hayward. USH 63 is functionally classified as rural principal arterial and belonging to factor group 6 (Tourist/Recreational Arterials and Collectors). The 2010 seasonal and daily factors for factor group 6 are presented in Table 6.2 for the months relevant to this study.

Table 6.2 2010 Daily and Seasonal Factors for Factor Group 6 (WisDOT, 2011)

Month	Dec		Jan		Feb		Mar		Apr		May	
	factor	sites	factor	sites	factor	sites	factor	sites	factor	sites	factor	sites
Seasonal	1.33	74	1.38*	27	1.24	77	1.24	77	1.12	77	0.94	77
Sunday	1.26	58	1.19	60	1.07	58	1.09	60	1.07	58	0.96	58
Monday	0.98	58	1.04	60	1.10	58	1.07	60	1.06	58	1.00	58
Tuesday	0.99	58	1.02	60	1.17	58	1.06	60	1.08	58	1.23	58
Wednesday	0.92	58	1.00	60	1.11	58	1.03	60	1.06	58	1.17	58
Thursday	0.91	58	1.01	60	0.98	58	1.00	60	1.00	58	1.07	58
Friday	0.88	58	0.85	60	0.80	58	0.84	60	0.82	58	0.80	58
Saturday	1.24	58	1.03	60	0.97	58	1.01	60	1.04	58	0.97	58
**No seasonal factor was available for January 2010 so 2009 January factor value was used.*												

For the FHWA class 9 vehicle example previously considered, the AADTT was estimated as follows:

$AADTT_{class9} = V_{24class9}$ x December seasonal factor x Monday (12/19/2011) daily factor
= 8 * 1.33 *0.98=10.4 → 10 veh/day.

Since daily factors are different for each day, AADTT was calculated for all days in a particular month for the various truck classes. The average value for a class represented the AADTT for that truck class for the given month.

Figure 6.2 shows the directional AADTT volume variation for the combined FHWA classes 6 to 13 for STH 27. Both directions indicate that peak truck traffic occurred in January during the winter months with the higher peak in the NB direction. In addition, there were more trucks loaded with logs in the winter months (Dec. 2011-Feb. 2012) in the NB direction with the peak occurring in February. The number of loaded logging trucks in February in the NB direction was approximately eight times that in the SB direction. During the same month, however, total empty logging truck volume in the SB direction was about double that in the NB direction. There were fewer logging trucks (loaded or empty) during the observed spring months (March-May) with minimal activity occurring in April for both directions.

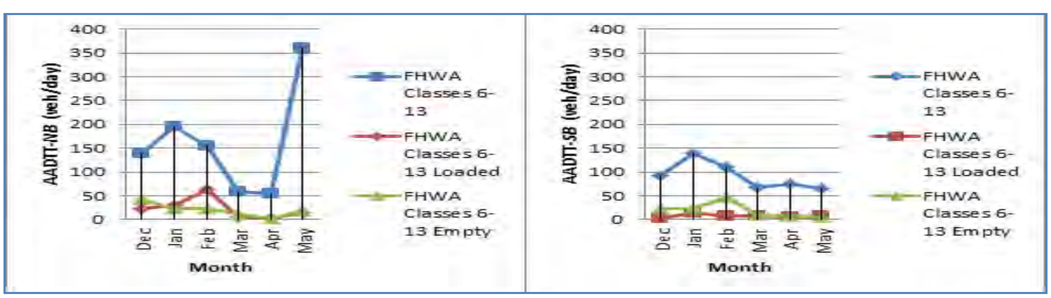


Figure 6.2 Directional AADTT Variations at STH 27 Control Station for Combined FHWA Vehicle Classes 6-13

The directional vehicle class by class breakdown of the AADTT is shown in Figure 6.3, which indicates that the predominant vehicular modes for log transportation along STH 27 include FHWA classes 9 and 10. During the peak period in February, these two vehicle classes carried nearly 97% (61/63) of all the log truck trips per day in the NB direction. In the SB direction, the peak period occurred in January and these two vehicle classes again carried nearly 93% (13/14) of all the log truck trips per day.

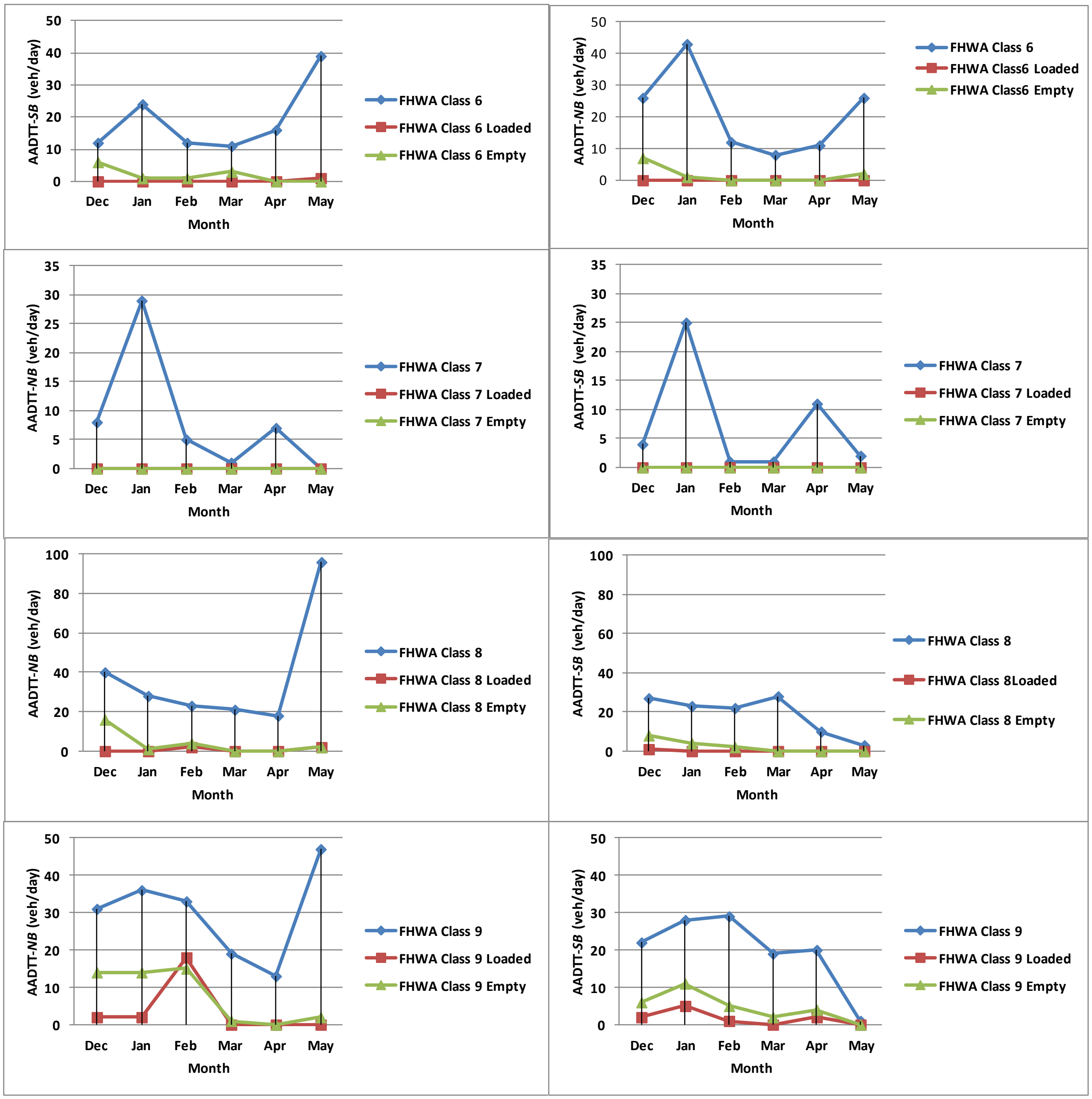


Figure 6.3 FHWA Vehicle Class by Class Directional AADTT variations at STH 27 Control Station

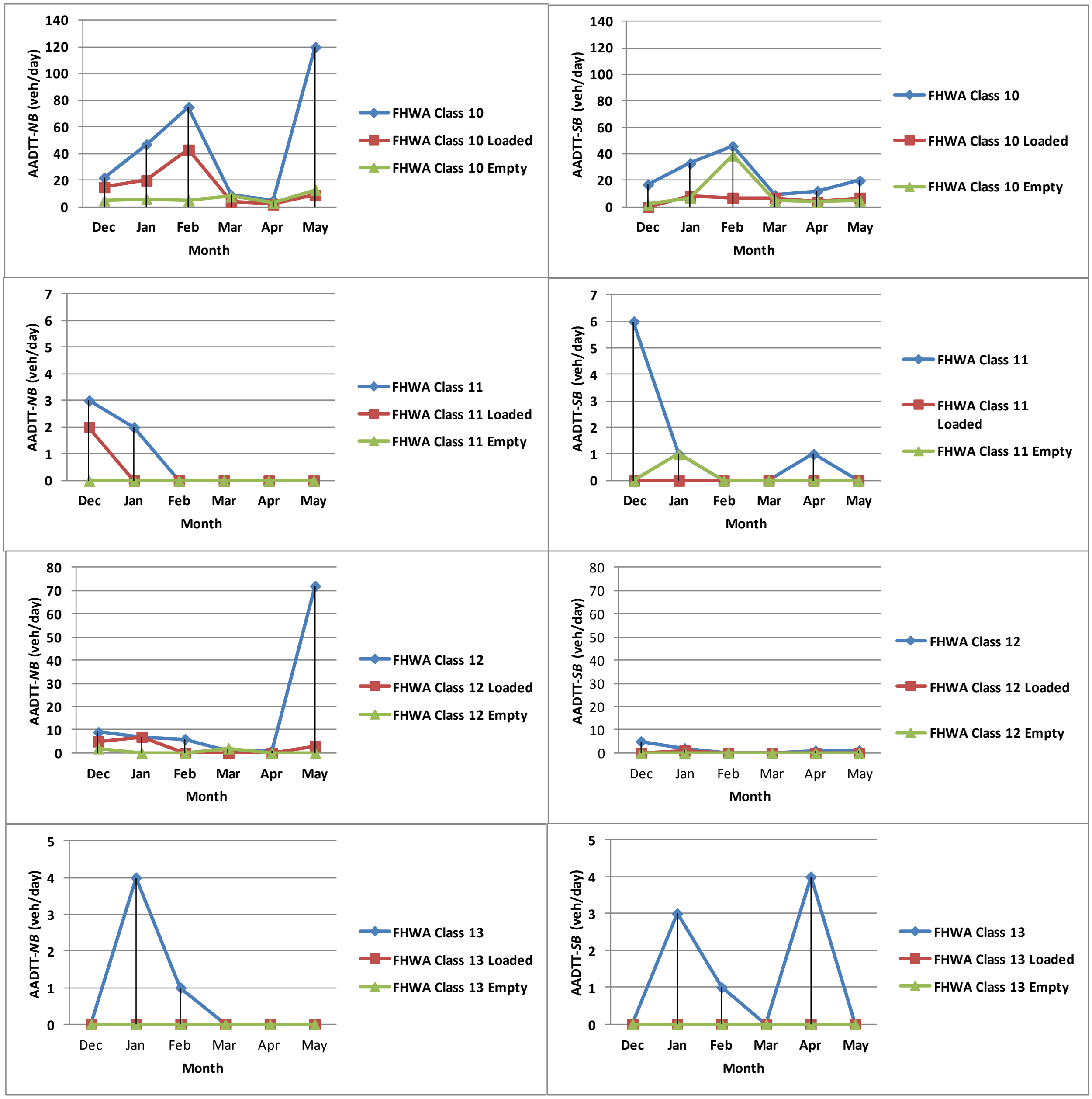


Figure 6.3 (Cont.)

6.2.2 STH 77 in Burnett and Washburn Counties

Two count locations on STH 77 were designated as coverage stations where short-term traffic counts were conducted once on specific weekdays during each of the study months with the aid of the Trax Flex HS™ automatic traffic data recorder and road tubes. One coverage station was set up approximately 100 feet west of Brooklyn Rd in Minong, Washburn County to capture traffic that traversed project segments from CTH H to USH 53. The other was set up on the east side of the bridge over the Canadian National Railway (see Figure 6.4) to capture traffic along project segments from Minong, at USH 53, to CTH M.

a) Minong coverage count location **b) Canadian National Railway coverage count location**

Figure 6.4 Coverage Count Locations on STH 77

Ideally, all stations would be counted the same way as the control stations but with a limited number of automatic traffic data recorders, full five-day counts were not feasible at all stations. Coverage stations had to be counted for at least a full day, but on some occasions, counters and road tubes had to be removed after a partial count because of snowfall and plowing activities. Unlike the control count stations which were supplemented by radar recorders, the coverage stations were not; hence, all partial counts had to be modified. The modification process consisted of the following:

a) Expansion of partial counts to full 24-hr volume counts;
b) Adjustment of expanded coverage counts by day of count using daily volume variation factor estimates derived from the control station;
c) Expansion of short-term visual logging truck counts to daily (24-hour volume) counts; and
d) Estimate of logging truck AADTT based on seasonal and daily adjustment factors.

6.2.2.1 Expansion of Coverage Counts on STH 77 to full 24-hr Volume Counts

Coverage count expansion relies solely on information from the control station. The assumption is made that control and coverage stations exhibit similar traffic volume patterns. Hence, the data from the control stations were used to expand the partial counts at the coverage stations to full 24-hr daily volume counts. An illustration of the procedure is depicted in the following example.

The total 24-hr volume count obtained on February 17, 2012 in the southbound (SB) direction at the STH 27 control station is shown in Table 6.3; while a partial count obtained in the westbound direction at the Minong coverage station on STH 77 for the same day from midnight through 2 p.m. is shown in Table 6.4. Beginning with the control station data, the total 24-hr volume was calculated to be 1613 vehicles per day. The total volume from midnight through 2 p.m. for the same control station was 1043 vehicles. Hence, the proportion of the latter volume in the overall 24-hr volume = 1043/1613 = 0.6499.

From Table 6.4, the total volume for the coverage station partial count data was 649. This was assumed to be 0.6499 of the total volume for the day based on the assumption that traffic volume pattern at the control station is similar to that at the coverage station. Hence, the total 24-hr volume for the coverage station = 649/0.6449 = 1004. The next step was to complete Table 6.4 for all hours for which traffic data were not directly collected (i.e., from 3 pm through 11 pm). The volumes can be computed as follows:

$$V_{Cvij} = \frac{V_{Ctij}}{\sum_{i=12AM}^{11PM} V_{Ctij}} * V_{CV24} \qquad 6.4$$

Where,

V_{cvij} = Estimated coverage station volume for time i for vehicle class j;
V_{ctij} = Control station volume for time i for vehicle class j;
V_{cv24} = Total estimated 24-hr volume for coverage station.

For example, 76 FHWA class 2 vehicles were counted at the control station from 3 p.m. to 4 p.m. The total volume at the coverage station for the same hour was calculated as: 76/1613 x 1004 = 47. The two related values (76 and 47) are circled in Tables 6.3 and 6.4, respectively.

Table 6.3 STH 27 Control Station Count for February in the SB Direction

Date	Time	FHWA Class 1	FHWA Class 2	FHWA Class 3	FHWA Class 4	FHWA Class 5	FHWA Class 6	FHWA Class 7	FHWA Class 8	FHWA Class 9	FHWA Class 10	FHWA Class 11	FHWA Class 12	FHWA Class 13	
2/17/2012	12:00 AM	0	4	4	0	3	0	0	0	0	0	0	0	0	Volume total:12AM thru 2PM=1043
2/17/2012	01:00 AM	0	7	2	0	0	0	0	0	0	0	0	0	0	
2/17/2012	02:00 AM	0	1	0	0	1	0	0	0	0	0	0	0	0	
2/17/2012	03:00 AM	0	4	0	0	1	0	0	0	0	0	0	0	0	
2/17/2012	04:00 AM	0	4	0	0	1	0	0	0	0	0	0	0	0	
2/17/2012	05:00 AM	0	5	1	0	3	0	0	0	0	1	0	0	0	
2/17/2012	06:00 AM	0	8	8	3	3	2	0	0	1	1	0	0	0	
2/17/2012	07:00 AM	0	22	25	2	14	2	0	2	0	2	0	0	0	
2/17/2012	08:00 AM	0	40	33	4	25	2	0	2	2	1	0	0	0	
2/17/2012	09:00 AM	0	44	31	1	26	0	0	2	3	1	0	0	0	
2/17/2012	10:00 AM	0	52	40	3	18	2	0	1	2	1	0	0	0	
2/17/2012	11:00 AM	0	69	61	1	21	0	0	3	0	3	0	0	0	
2/17/2012	12:00 PM	0	64	55	5	28	0	0	2	3	2	0	0	1	
2/17/2012	01:00 PM	0	81	55	0	35	2	0	4	2	3	0	0	0	
2/17/2012	02:00 PM	0	25	33	1	10	0	0	0	1	0	0	0	0	Total Daily volume=1613
2/17/2012	03:00 PM	1	76	28	1	2	0	0	2	2	0	0	0	0	
2/17/2012	04:00 PM	1	78	29	1	3	0	0	2	2	0	0	0	0	
2/17/2012	05:00 PM	1	66	25	1	2	0	0	2	2	0	0	0	0	
2/17/2012	06:00 PM	0	54	20	1	2	0	0	2	1	0	0	0	0	
2/17/2012	07:00 PM	0	39	15	0	1	0	0	1	1	0	0	0	0	
2/17/2012	08:00 PM	0	29	11	0	1	0	0	1	1	0	0	0	0	
2/17/2012	09:00 PM	0	22	8	0	1	0	0	1	1	0	0	0	0	
2/17/2012	10:00 PM	0	14	5	0	0	0	0	0	0	0	0	0	0	
2/17/2012	11:00 PM	0	8	3	0	0	0	0	0	0	0	0	0	0	

Table 6.4 STH 77 Westbound Coverage Data Expanded to 24-hr Volume

Date	Time	FHWA Class 1	FHWA Class 2	FHWA Class 3	FHWA Class 4	FHWA Class 5	FHWA Class 6	FHWA Class 7	FHWA Class 8	FHWA Class 9	FHWA Class 10	FHWA Class 11	FHWA Class 12	FHWA Class 13	
2/17/2012	12:00 AM	0	1	2	0	0	0	0	0	0	0	0	0	0	
2/17/2012	01:00 AM	0	1	0	0	0	0	0	0	0	0	0	0	0	Total volume from 12AM thru 2PM=649
2/17/2012	02:00 AM	0	1	0	0	0	0	0	0	1	0	0	0	0	
2/17/2012	03:00 AM	0	2	1	0	0	0	0	0	0	0	0	0	0	
2/17/2012	04:00 AM	0	10	4	0	0	0	0	0	1	0	0	0	0	
2/17/2012	05:00 AM	0	18	5	0	0	0	0	0	0	3	0	0	0	
2/17/2012	06:00 AM	0	18	7	0	0	1	0	0	0	1	0	0	0	
2/17/2012	07:00 AM	0	43	15	3	1	0	0	0	0	1	0	0	0	
2/17/2012	08:00 AM	0	47	19	0	4	0	0	0	1	0	0	0	0	
2/17/2012	09:00 AM	0	27	20	0	5	0	0	0	0	1	0	0	0	
2/17/2012	10:00 AM	0	37	17	1	2	1	0	1	5	4	0	0	0	
2/17/2012	11:00 AM	0	45	24	0	6	0	1	1	1	0	0	0	0	
2/17/2012	12:00 PM	0	59	16	0	6	1	0	0	0	2	0	0	0	
2/17/2012	01:00 PM	0	38	22	0	11	0	0	1	1	1	0	0	0	
2/17/2012	02:00 PM	0	49	25	0	4	0	0	1	0	2	0	0	0	
2/17/2012	03:00 PM	1	47	17	1	1	0	0	1	1	0	0	0	0	
2/17/2012	04:00 PM	1	49	18	1	2	0	0	1	1	0	0	0	0	
2/17/2012	05:00 PM	1	41	16	1	1	0	0	1	1	0	0	0	0	
2/17/2012	06:00 PM	0	34	12	1	1	0	0	1	1	0	0	0	0	
2/17/2012	07:00 PM	0	24	9	0	1	0	0	1	1	0	0	0	0	
2/17/2012	08:00 PM	0	18	7	0	1	0	0	1	1	0	0	0	0	
2/17/2012	09:00 PM	0	14	5	0	1	0	0	1	1	0	0	0	0	
2/17/2012	10:00 PM	0	9	3	0	0	0	0	0	0	0	0	0	0	
2/17/2012	11:00 PM	0	5	2	0	0	0	0	0	0	0	0	0	0	

6.2.2.2 STH 77 Coverage Count Daily Volume Adjustments

Coverage volumes needed to be further adjusted to reflect the average day of the monthly five-day study period undertaken at the control stations. This required the use of daily volume variation factors, which were derived from the control station counts. Roess et al. (2004) recommended equation 6.5 for adjusting coverage count data.

$$V_a = V_i * F_{vi} \qquad (6.5)$$

Where, V_a = Volume for the average day of study period, vehs;

V_i = Volume for day i;

F_{vi} = Adjustment factor for day i.

The adjustment factors were calculated by direction and are illustrated in the example computation in Table 6.5 for the southbound traffic along STH 27 for the month of February 2012. A summary of all adjustment factors for the STH 27 control station is shown in Table 6.6. Using the factors from Table 6.6, all 24-hr volume coverage counts served by the STH 27 control station were adjusted accordingly based on the day the coverage count was taken. The final modified coverage data from Table 6.4 based on a daily volume variation factor of 1.33 (see Table 6.5) are presented in Table 6.7.

Table 6.5 Daily volume variation adjustment factor estimate for SB traffic on STH 27 (February 2012 data)

Date	Day	Total SB daily volume,vpd	Daily Adjustment Factor, F_{vi}
2/13/12	Monday	2153	2152/2153=1.00
2/14/12	Tuesday	2367	2152/2367= 0.91
2/15/12	Wednesday	2309	2152/2309=0.93
2/16/12	Thursday	2317	2152/2317=0.93
2/17/12	Friday	1613	2152/1613 =1.33
Average Volume= (2153+2367+2309+2317+1613)/5=2,152			

Table 6.6 Daily Volume Variation Factors for STH 27 Control Station

Date	Day	Daily volume variation factor by direction	
		NB	SB
12/19/11	Monday	1.25	0.96
12/20/11	Tuesday	1.15	0.88
12/21/11	Wednesday	1.12	0.92
12/22/11	Thursday	1.19	0.90
12/23/11	Friday	0.63	1.60
1/09/12	Monday	1.16	0.92
1/10/12	Tuesday	1.19	0.92
1/11/12	Wednesday	1.09	0.93
1/12/12	Thursday	1.07	0.98
1/13/12	Friday	0.69	1.36
2/13/12	Monday	1.12	1.00
2/14/12	Tuesday	1.05	0.91
2/15/12	Wednesday	1.10	0.93
2/16/12	Thursday	1.07	0.93
2/17/12	Friday	0.77	1.33
3/19/12	Monday	1.07	1.10
3/20/12	Tuesday	1.11	1.10
3/21/12	Wednesday	1.04	0.94
3/22/12	Thursday	1.06	1.06
3/23/12	Friday	0.79	0.86
4/16/12	Monday	1.28	1.07
4/17/12	Tuesday	1.11	0.87
4/18/12	Wednesday	1.21	0.95
4/19/12	Thursday	1.15	0.92
4/20/12	Friday	0.62	1.31
5/14/12	Monday	1.09	1.03
5/15/12	Tuesday	1.06	1.03
5/16/12	Wednesday	1.02	0.98
5/17/12	Thursday	1.00	1.01
5/18/12	Friday	0.87	0.96

Table 6.7 STH 77 Westbound Coverage Data Adjusted by Daily Volume Variation Factor

Date	Time	FHWA Class 1	FHWA Class 2	FHWA Class 3	FHWA Class 4	FHWA Class 5	FHWA Class 6	FHWA Class 7	FHWA Class 8	FHWA Class 9	FHWA Class 10	FHWA Class 11	FHWA Class 12	FHWA Class 13
2/17/2012	12:00 AM	0	1	3	0	0	0	0	0	0	0	0	0	0
2/17/2012	01:00 AM	0	1	0	0	0	0	0	0	0	0	0	0	0
2/17/2012	02:00 AM	0	1	0	0	0	0	0	0	1	0	0	0	0
2/17/2012	03:00 AM	0	3	1	0	0	0	0	0	0	0	0	0	0
2/17/2012	04:00 AM	0	13	5	0	0	0	0	0	1	0	0	0	0
2/17/2012	05:00 AM	0	24	7	0	0	0	0	0	0	4	0	0	0
2/17/2012	06:00 AM	0	24	9	0	0	1	0	0	0	2	0	0	0
2/17/2012	07:00 AM	0	57	20	4	1	0	0	0	0	2	0	0	0
2/17/2012	08:00 AM	0	63	25	0	5	0	0	0	3	0	0	0	0
2/17/2012	09:00 AM	0	36	27	0	7	0	0	0	0	2	0	0	0
2/17/2012	10:00 AM	0	49	23	1	3	1	0	1	7	5	0	0	0
2/17/2012	11:00 AM	0	60	32	0	8	0	1	1	1	0	0	2	0
2/17/2012	12:00 PM	0	78	21	0	8	1	0	0	0	3	0	0	0
2/17/2012	01:00 PM	0	51	29	0	15	0	0	1	3	1	0	1	0
2/17/2012	02:00 PM	0	65	33	0	5	0	0	1	0	3	0	2	0
2/17/2012	03:00 PM	1	63	23	1	2	0	0	2	2	0	0	0	0
2/17/2012	04:00 PM	1	65	24	1	2	0	0	2	4	0	0	0	0
2/17/2012	05:00 PM	1	55	21	1	2	0	0	2	2	0	0	0	0
2/17/2012	06:00 PM	0	45	17	1	2	0	0	2	1	0	0	0	0
2/17/2012	07:00 PM	0	32	12	0	1	0	0	1	1	0	0	0	0
2/17/2012	08:00 PM	0	24	9	0	1	0	0	1	1	0	0	0	0
2/17/2012	09:00 PM	0	18	7	0	1	0	0	1	1	0	0	0	0
2/17/2012	10:00 PM	0	12	4	0	0	0	0	0	0	0	0	0	0
2/17/2012	11:00 PM	0	7	2	0	0	0	0	0	0	0	0	0	0

6.2.2.3 Expansion and Conversion of STH 77 Logging Truck Volumes to AADTT

Sample visual logging truck counts were obtained at coverage station locations on STH 77 on the same days that traffic volume counts were obtained using the Trax Flex HS^{TM} automatic traffic data recorders. The visual counts were expanded to full 24-hr daily counts and the AADTT calculated based on procedures previously described for the STH 27 control station. The directional AADTT variation for the combined FHWA classes 6 through 13 are shown in Figure 6.5 for the Minong coverage station, while the vehicle class-by-class variations are shown in Figure 6.6. Figure 6.5 suggests that loaded truck movements occurred *only* in the EB direction from January to May, while empty truck movements occurred *only* in the WB direction for the same period. The peak loading occurred in February and April while the minimum loading occurred in March and May. The peak for empty logging trucks occurred in February with the minimum occurring in March.

The vehicle class by class analysis suggests that FHWA classes 9 and 10 are the main carriers of logs along the portion of STH 77 studied. Class 9 carried more logs during the peak month of February compared to class 10. The reverse is true during the peak month of April where class 10 carried the bulk of the load. Empty truck volume activity was dominated by class 10 in the WB direction throughout the study period. Empty truck movement for class 9 was at its peak in February but diminished from March to May.

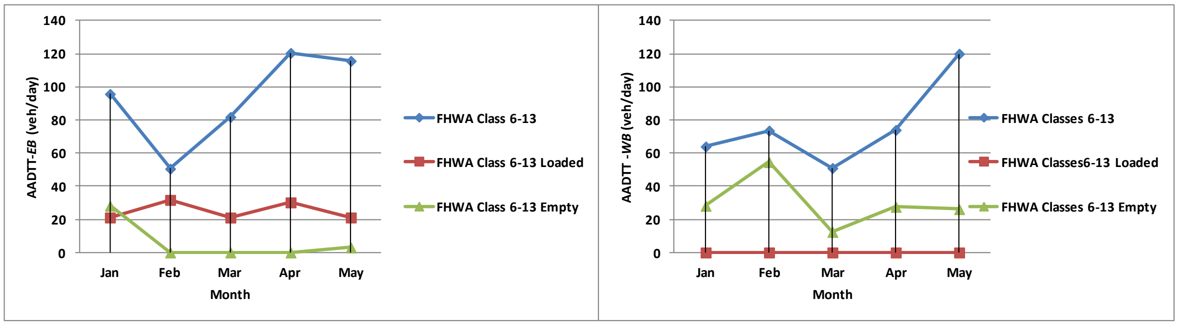


Figure 6.5 Directional Volume variations at STH 77 Coverage Station at Minong

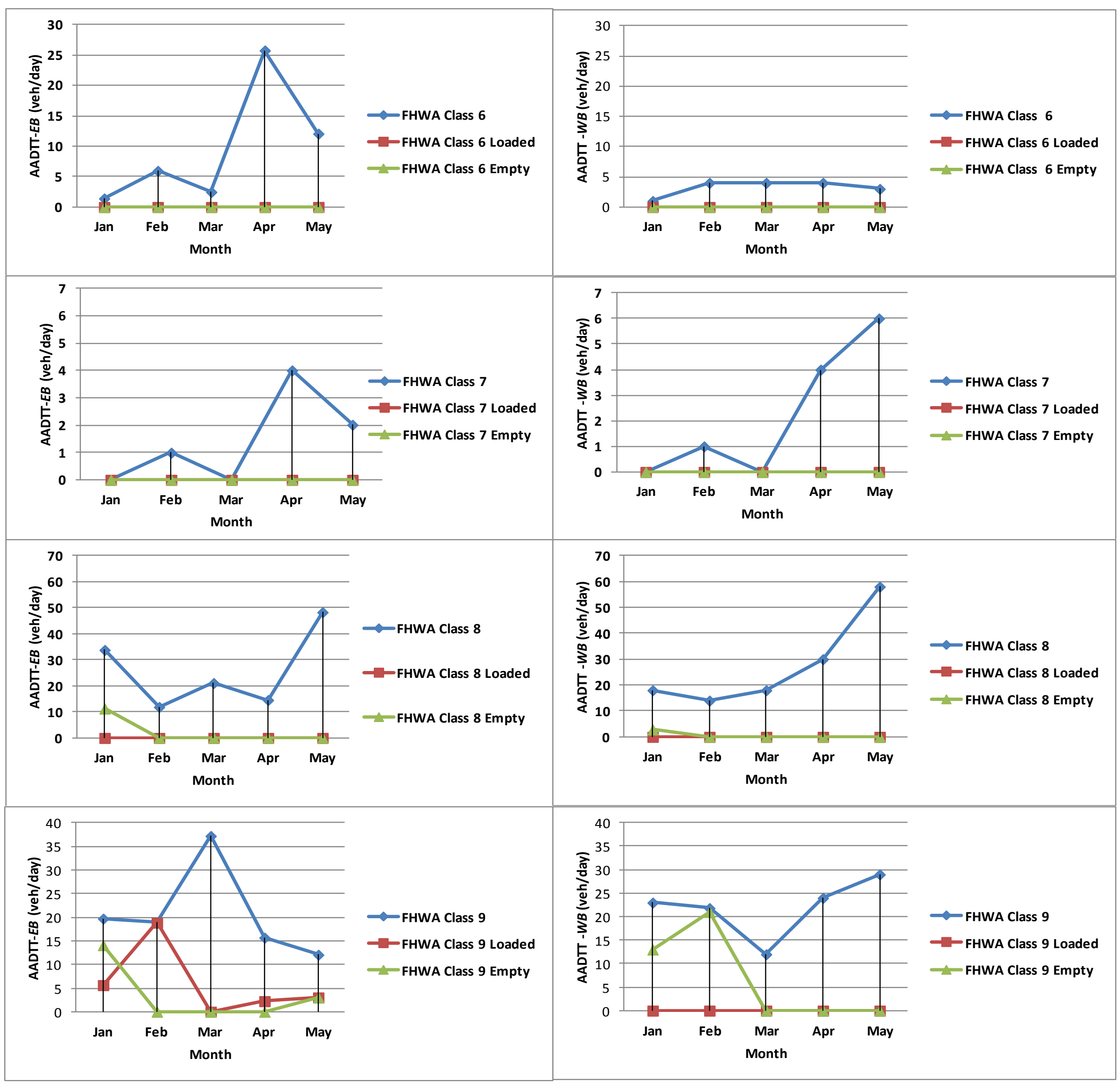


Figure 6.6 FHWA Vehicle Class by Class Directional Volume Variations at the STH 77 Coverage Station at Minong

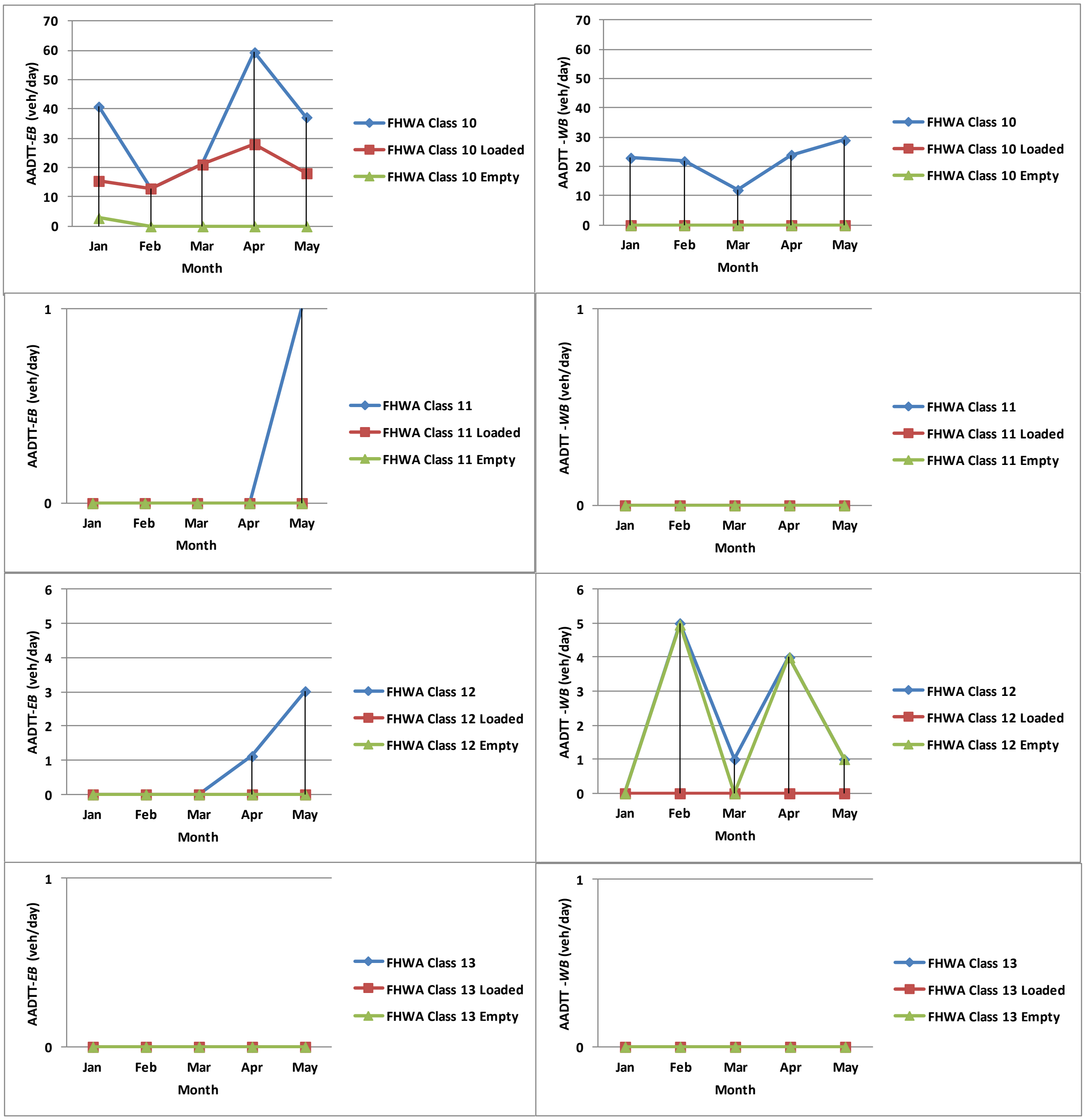


Figure 6.6 (Cont.)

The traffic characteristics for the STH 77 coverage station at the Canadian National Railway (CNR) bridge can be found in Figures 6.7 and 6.8. Figure 6.7 indicates that peak loaded logging truck movements occurred in January for both directions but with higher volumes in the EB direction. Loading activity stopped in March for the WB direction while it continued throughout the entire study period for the EB. Empty logging truck movement varied considerably for both directions. It peaked in the WB direction in January but no activity occurred in the following months until April and May. The EB empty logging activity peaked in February but did not experience any activity until May.

The vehicle class by class variation shown in Figure 6.8 suggests that vehicle classes 9 and 10 were the main carriers of logs predominantly in the EB direction. Vehicle class 10 however, carried more logs per day throughout the study period.

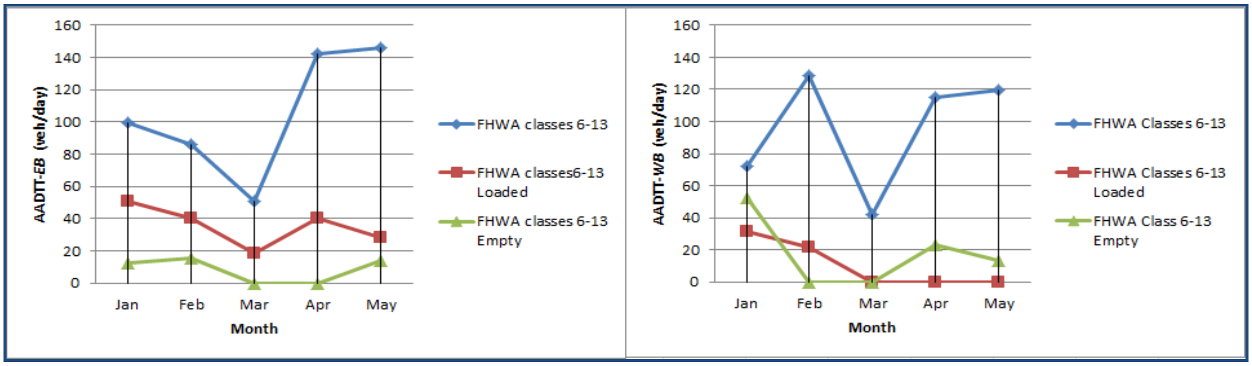


Figure 6.7 Directional Volume Variations at STH 77 Coverage Station near CNR Bridge

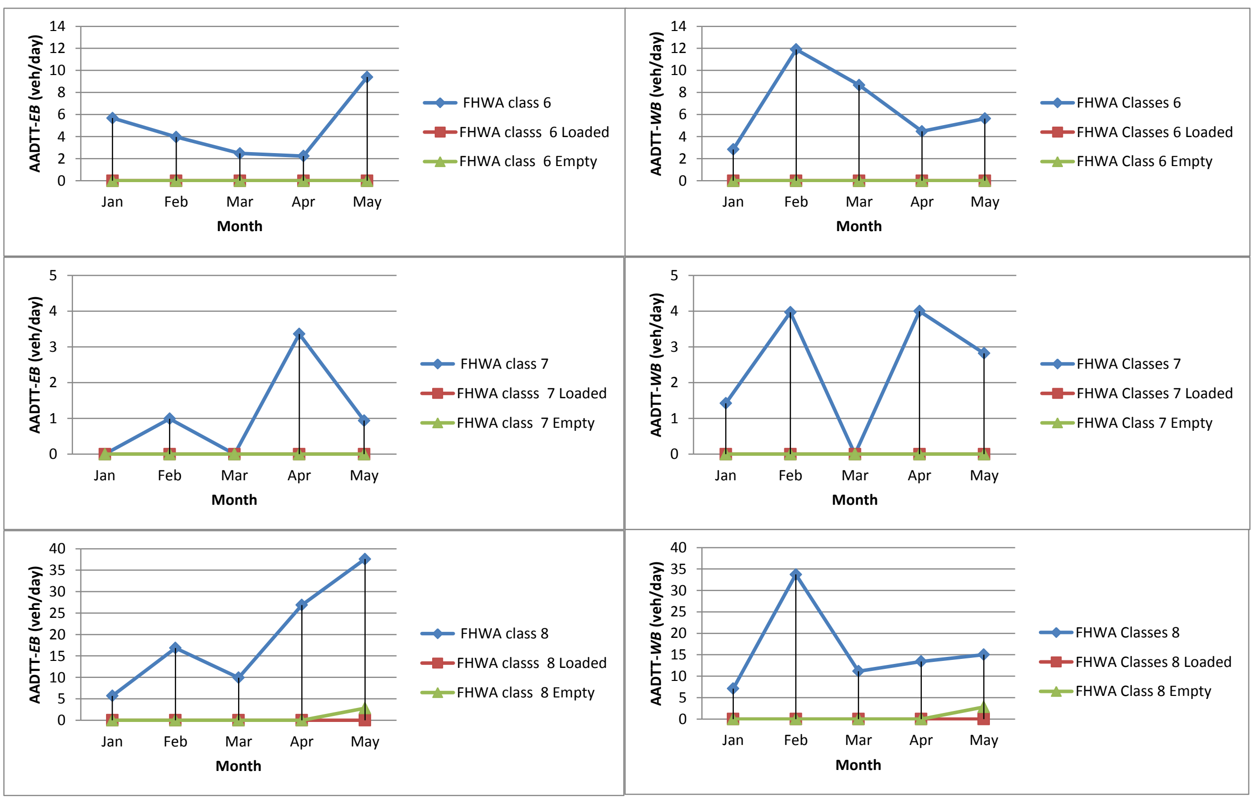


Figure 6.8 FHWA Vehicle Class Directional Volume variations at STH 77 Coverage Station at CNR bridge

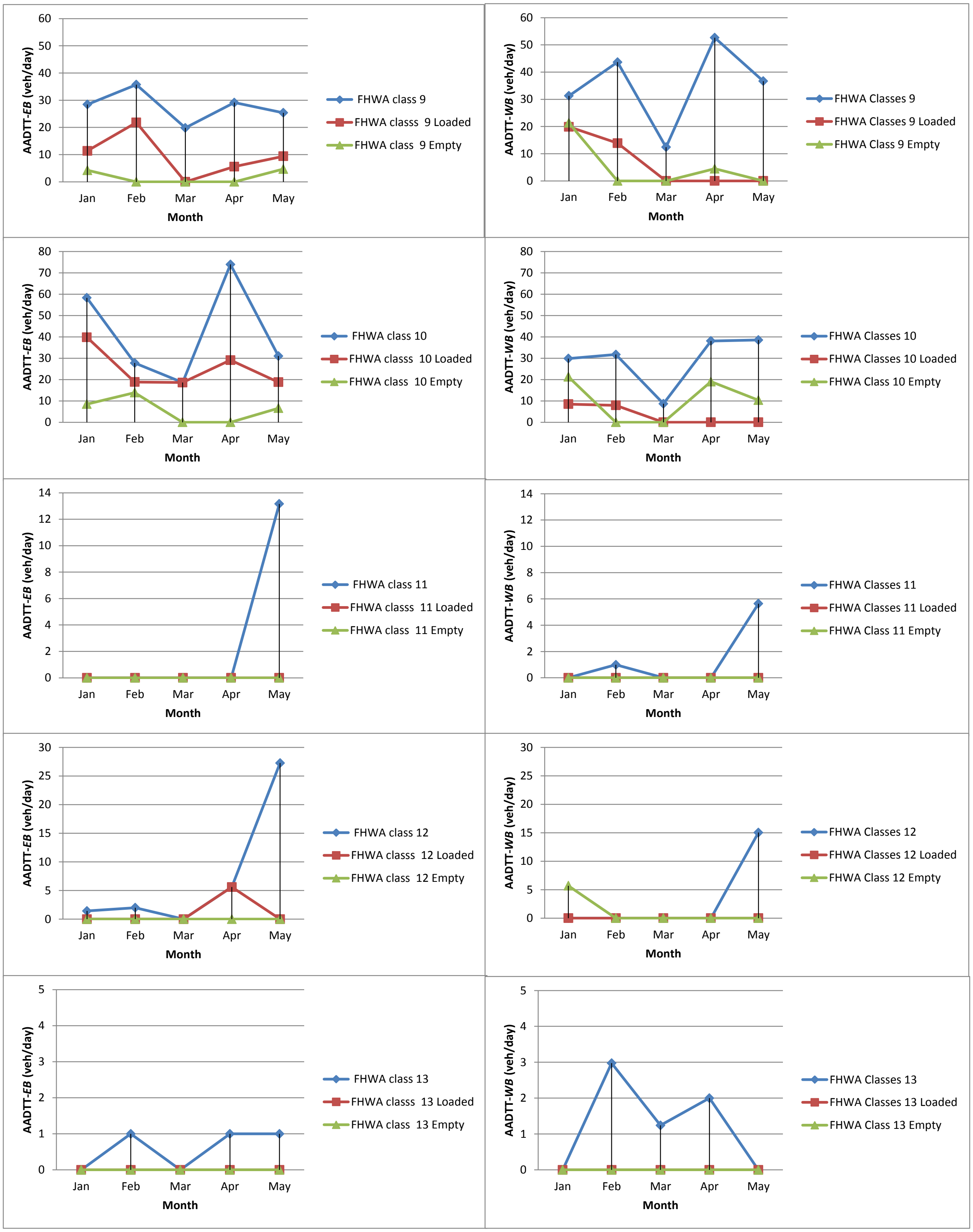


Figure 6.8 (Cont.)

6.2.3 STH 27/70 at Radisson

Another control count station was established just west of N. Martin Avenue in the Village of Radisson (see Figure 6.9) to collect data along STH 27/70 for project segments from Radisson to Ojibwa and STH 40 to CTH C. AADTT estimates followed similar computations performed for the STH 27 control station in Hayward. Seasonal and daily factors used were established using information from the nearest WisDOT continuous count station which happened to be Site #540001.6635.NW located along STH 27. The site is 2.0 miles North of CTH J East-Ladysmith, Rusk County. The functional class is described as Rural Minor Arterial-Other and further classified as belonging to seasonal and daily factor group 6 (WisDOT 2011g). Hence, factor group 6 seasonal and daily factor data found in Table 6.2 were used in the AADTT estimates for this control station and all related coverage stations.

Figure 6.9 Control Count Station Location on STH 27/70

Figure 6.10 shows the AADTT variation for the combined FHWA vehicle classes 6-13. Loaded logging truck activity was highest in the EB direction in December; it approached 60 loaded trucks per day and declined gradually to one loaded truck per day in March. It did pick up in April and increased in May to about 9 trucks per day. The WB loaded truck activity on the other hand, rose gradually from zero in December to a peak value of 32 loaded trucks per day in February. It declined to an average of 3 loaded trucks in March and April before reaching a daily value of 8 loaded trucks in May. Overall, there were *twice* as many loaded trucks in the EB direction than in the WB direction during the study period. During the same period, there were more empty trucks in the WB direction than in the EB direction.

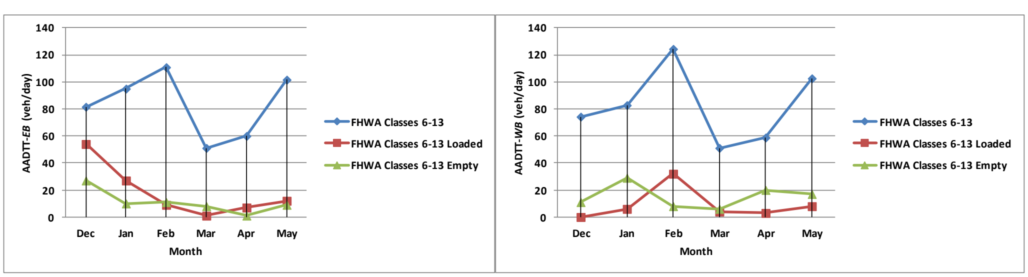


Figure 6.10 Directional AADTT Variations at STH 27/70 Control Station for Combined FHWA Vehicle Classes 6-13

The class-by-class variation shown in Figure 6.11 indicates vehicle classes 9 and 10 were the main carriers of logs along the section of STH 27/70 studied. Classes 6, 8, 9, 10, and 12 empty logging trucks were found along the study segment, but classes 9 and 10 dominated the empty truck population.

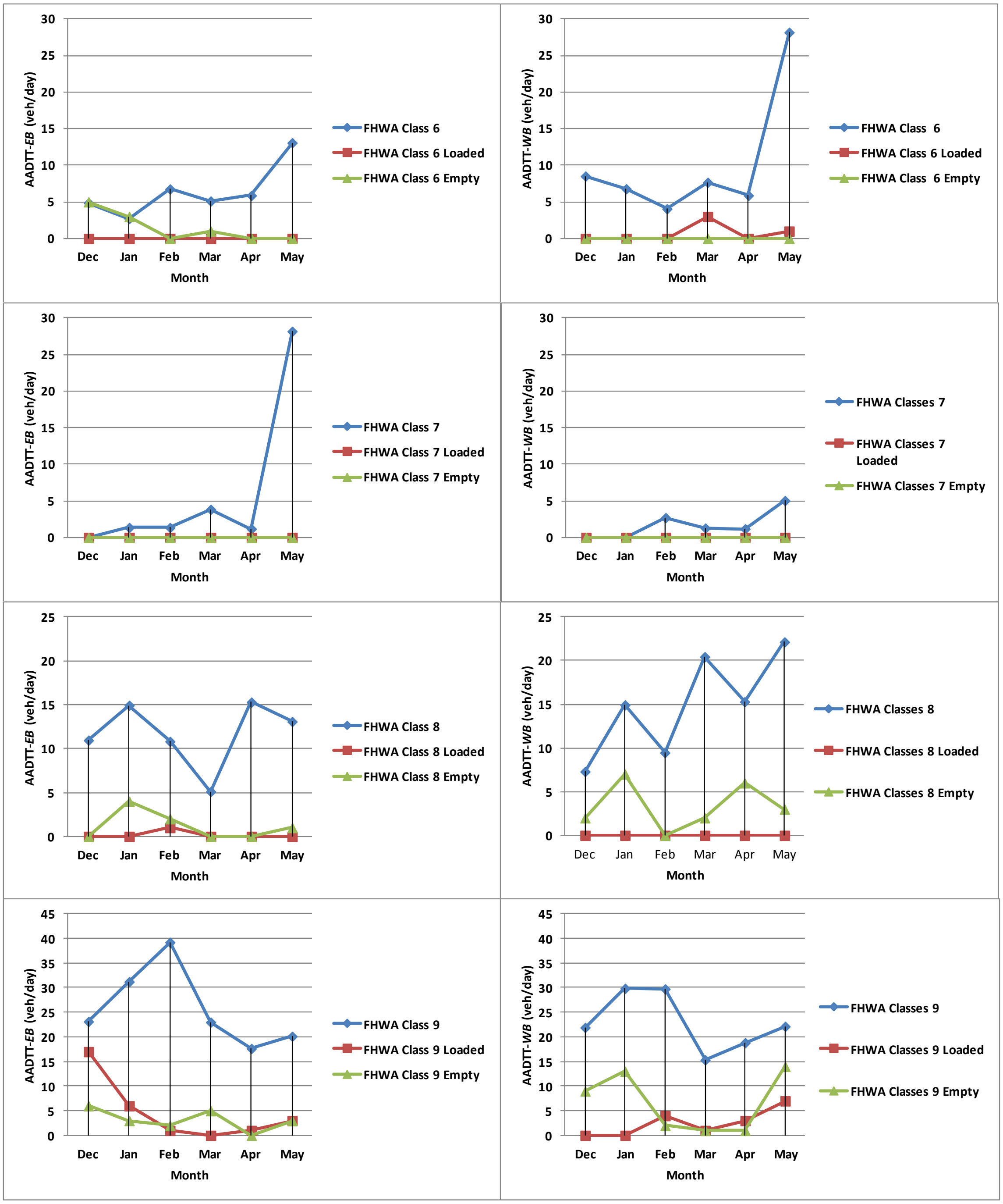


Figure 6.11 FHWA Vehicle Class Directional Volume Variations at STH 27/70 Control Station at Radisson

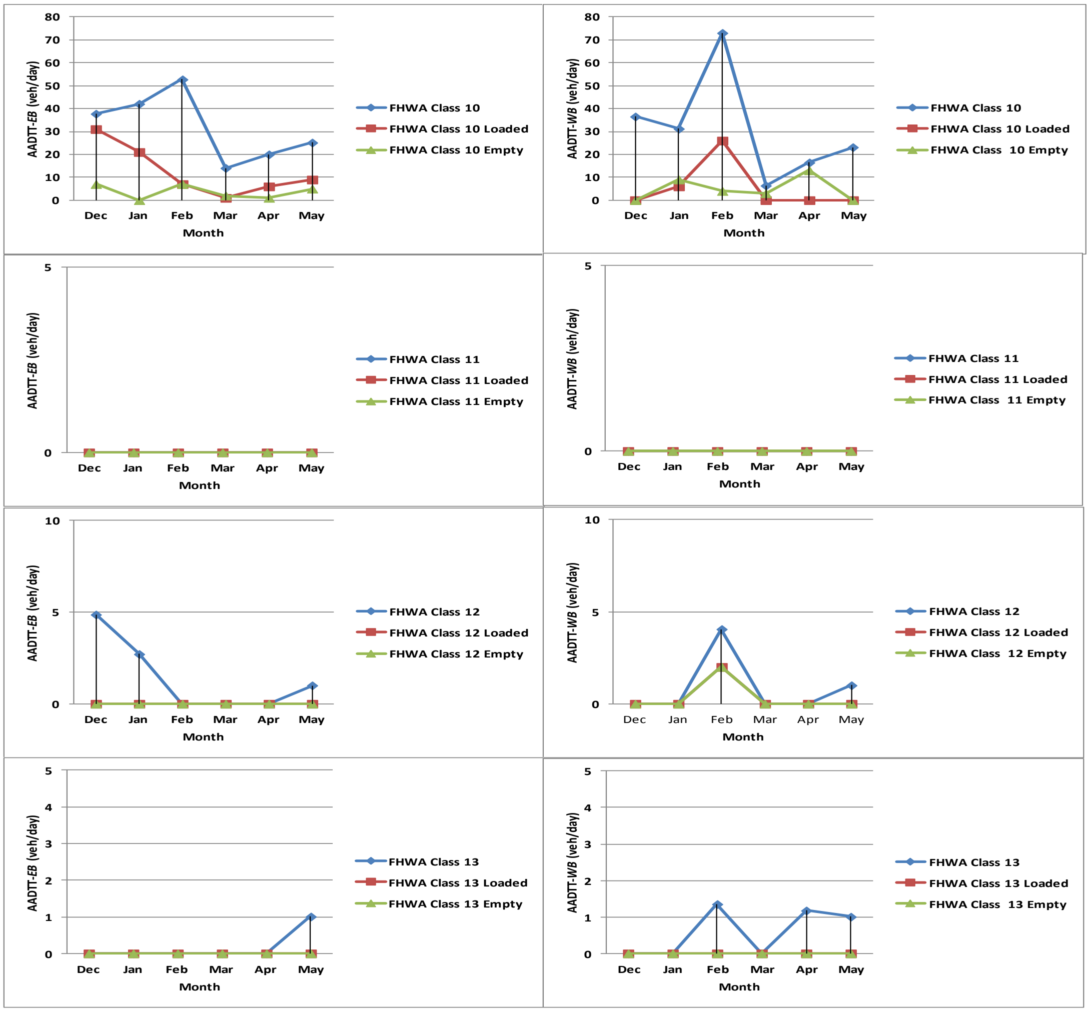


Figure 6.11 (Cont.)

6.2.4 STH 27 at Thornapple River Bridge Crossing

The coverage station for STH 27 segment from Ojibwa to Ladysmith was located at the southside of the Thornapple river bridge crossing (see Figure 6.12) in Rusk county.

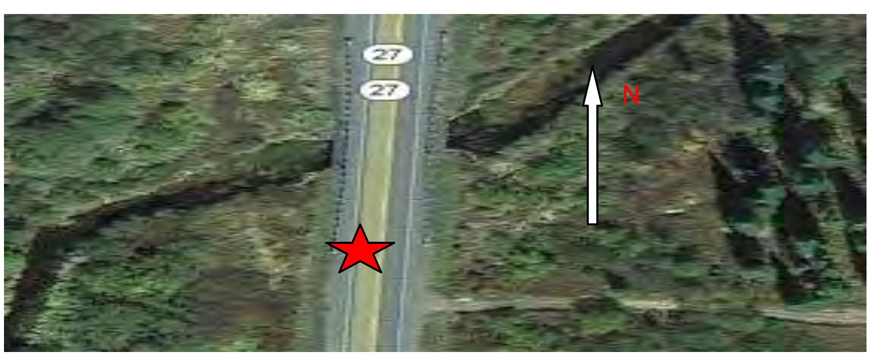


Figure 6.12 STH 27 Coverage Count Location at the Thornapple River Bridge Crossing

All partial count volumes were expanded to 24-hr counts and adjusted using daily volume variation factors derived from the STH 27/70 control station. The factors are summarized in Table 6.8. The adjusted volumes were converted to AADTT using seasonal and daily factors corresponding to factor group 6 presented earlier in Table 6.2.

Table 6.8 Daily Volume Variation Factors for STH 27/70 Control Station

Date	Day	Daily Volume Variation Factors	
		EB	WB
12/19/11	Monday	-	-
12/20/11	Tuesday	0.95	0.78
12/21/11	Wednesday	1.16	1.10
12/22/11	Thursday	1.10	1.10
12/23/11	Friday	0.85	1.10
1/09/12	Monday	1.24	1.11
1/10/12	Tuesday	1.01	0.89
1/11/12	Wednesday	0.83	1.02
1/12/12	Thursday	-	-
1/13/12	Friday	-	-
2/13/12	Monday	0.94	0.83
2/14/12	Tuesday	1.05	1.02
2/15/12	Wednesday	1.09	1.06
2/16/12	Thursday	1.07	1.06
2/17/12	Friday	0.88	1.08
3/19/12	Monday	1.10	1.00
3/20/12	Tuesday	1.04	0.95
3/21/12	Wednesday	1.03	1.04
3/22/12	Thursday	1.03	0.96
3/23/12	Friday	0.84	1.06
4/16/12	Monday	1.25	1.19
4/17/12	Tuesday	1.05	1.00
4/18/12	Wednesday	1.09	1.01
4/19/12	Thursday	0.99	0.92
4/20/12	Friday	0.96	0.93
5/14/12	Monday	1.09	1.03
5/15/12	Tuesday	1.07	1.07
5/16/12	Wednesday	1.02	0.97
5/17/12	Thursday	0.98	1.01
5/18/12	Friday	0.87	0.93

The STH 27 Rusk County AADTT variations for the combined FHWA classes 6-13 are shown in Figure 6.13, which suggests that loaded logging truck movement was predominantly in the SB direction with a peak average of 23 loaded trucks per day in December and February, and then dwindling to 3 trucks per day in March. February was the only month that loading activity occurred in the NB direction with six loaded trucks per day.

The class-by-class variations are shown in Figure 6.14. Classes 9 and 10 carried nearly 100% of the daily loaded trucks in the SB direction during the study period.

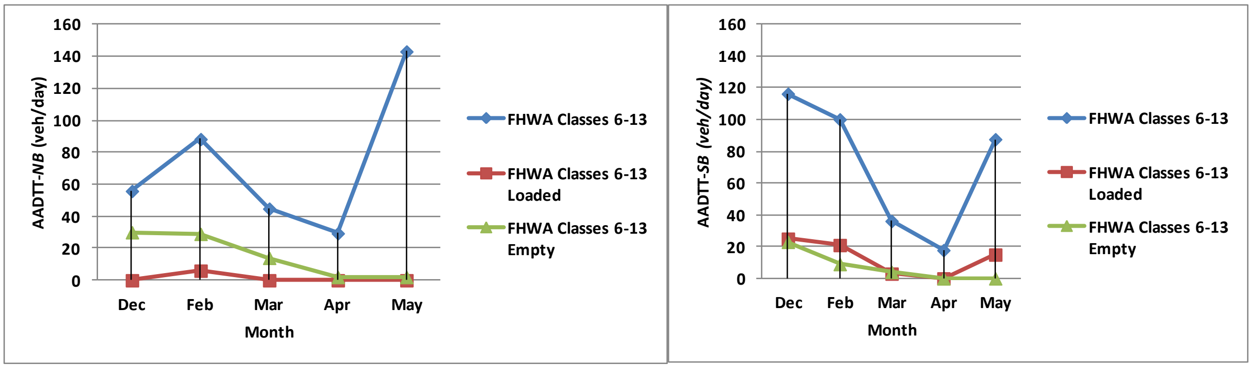


Figure 6.13 Directional Combined FHWA Vehicle Classes 6-13 AADTT Variation at STH 27 Coverage Station at the Thornapple River Bridge Crossing

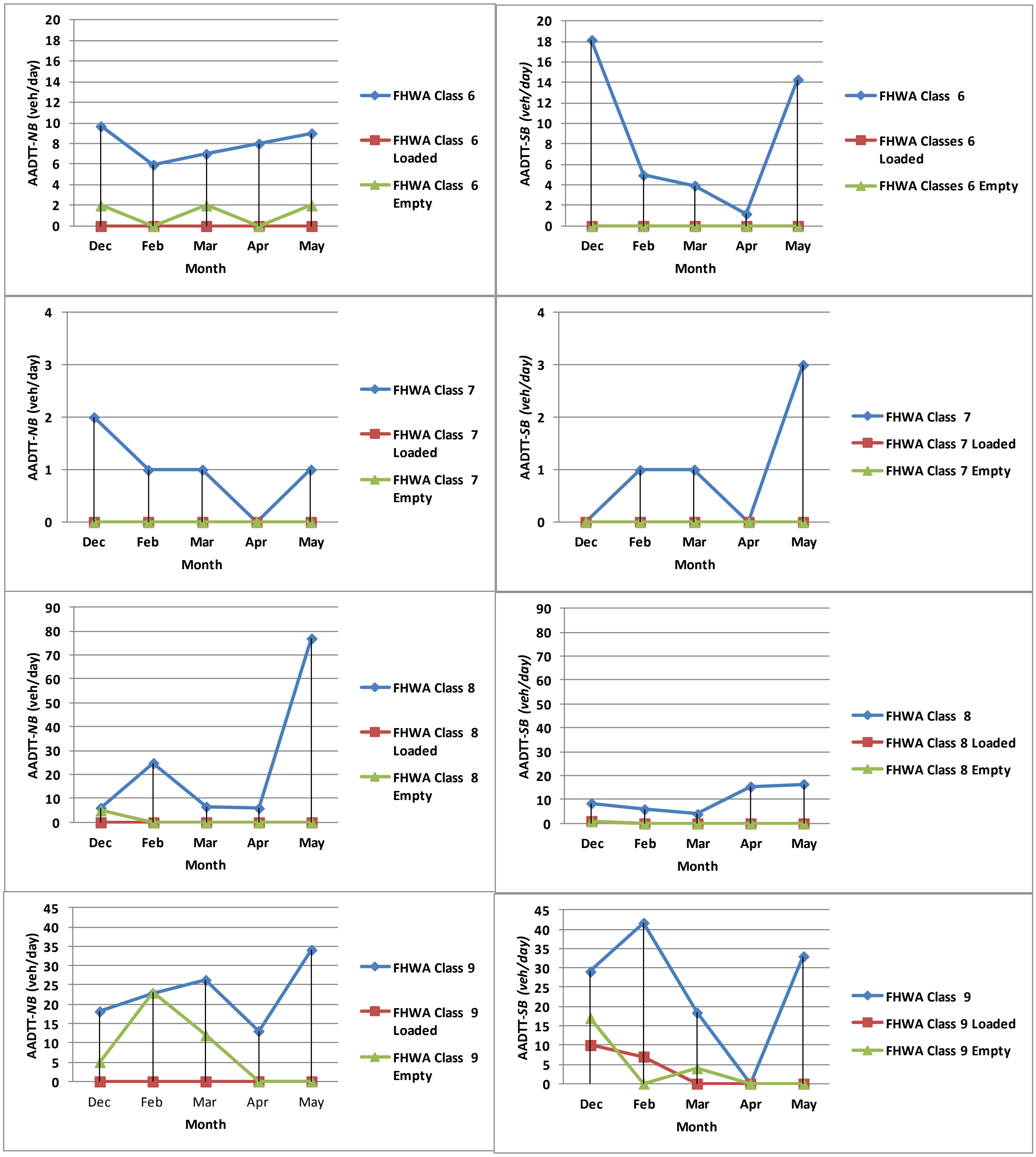


Figure 6.14 FHWA Vehicle Class Directional Volume variations at STH 27 Coverage Station at the Thornapple River Bridge Crossing

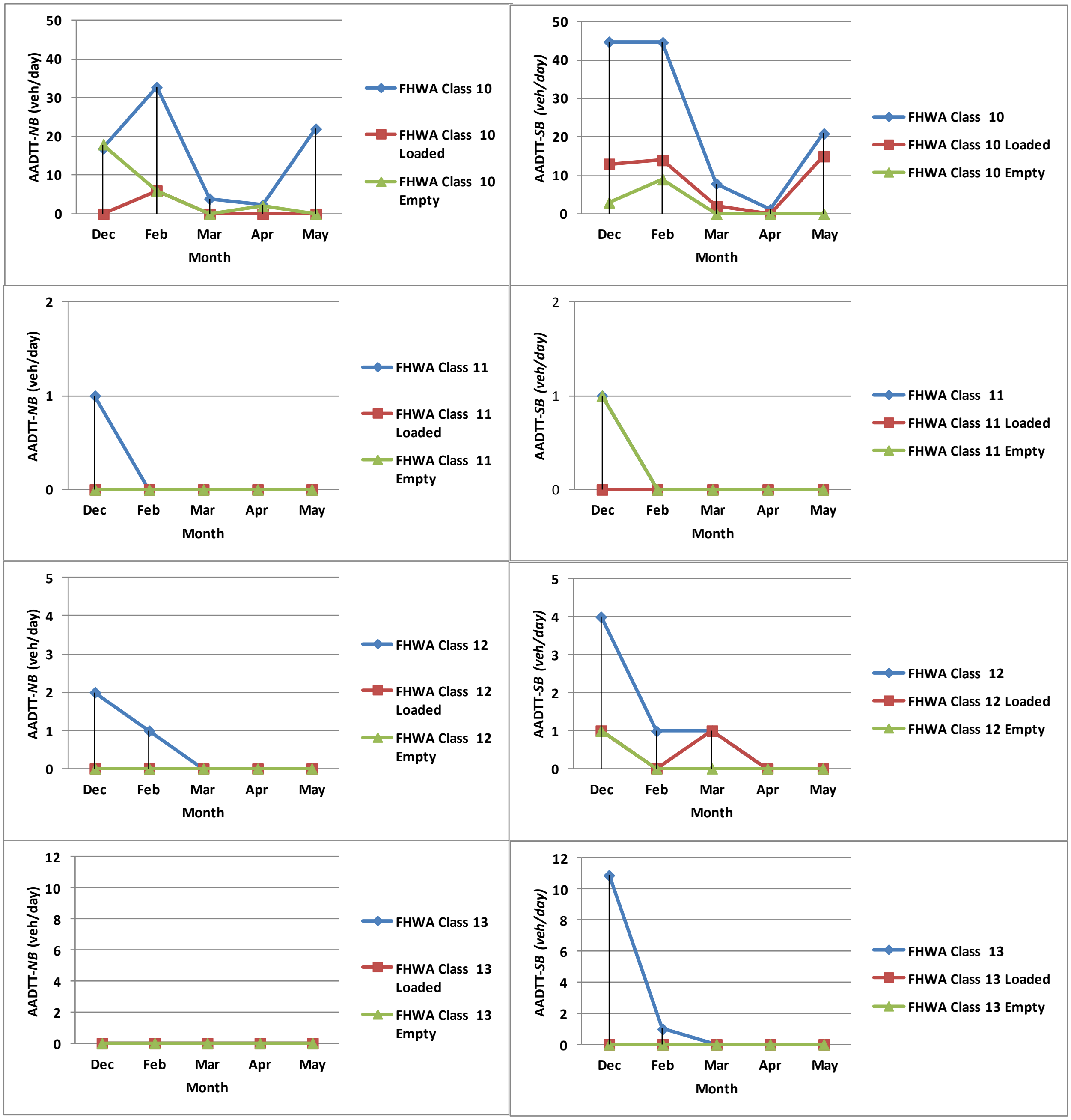


Figure 6.14 (Cont.)

6.2.5 STH 48 in Sawyer County

The coverage station for STH 48 was set up on the eastside of the Canadian National Railway line between Fetting Ln and Polish Rd in the Town of Wiergor (see Figure 6.15). AADTT variations for the combined FHWA classes 6-13 trucks are shown in Figure 6.16. Loaded logging truck activity occurred in the EB direction for December only, averaging 21 trucks per day. No loaded logging truck activity occurred in the WB direction during the entire study period. Empty logging trucks were however, observed in both directions for December only with the higher volume (9 trucks per day) occuring in the WB direction.

The truck class-by-class observations (see Figure 6.17) indicate that classes 8, 9, 10, and 12 were carriers of logs in the EB direction in December. Class 9 had the largest share of nine trucks/day followed by class 12 with six daily trucks. Classes 8 and 10 together combined for six trucks per day. Empty logging truck traffic was dominated by class 9 in both directions.

Figure 6.15 Counter Location at STH 48 Coverage Station at Wiergor

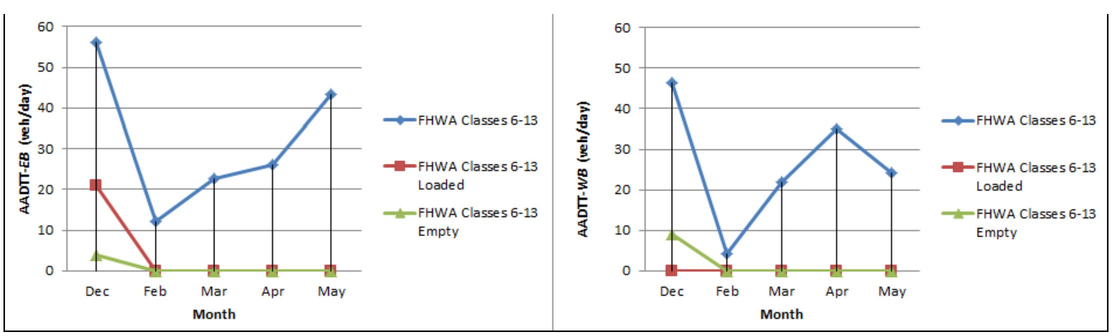


Figure 6.16 Combined FHWA Classes 6-13 AADTT Variations for STH 48 at Wiergor

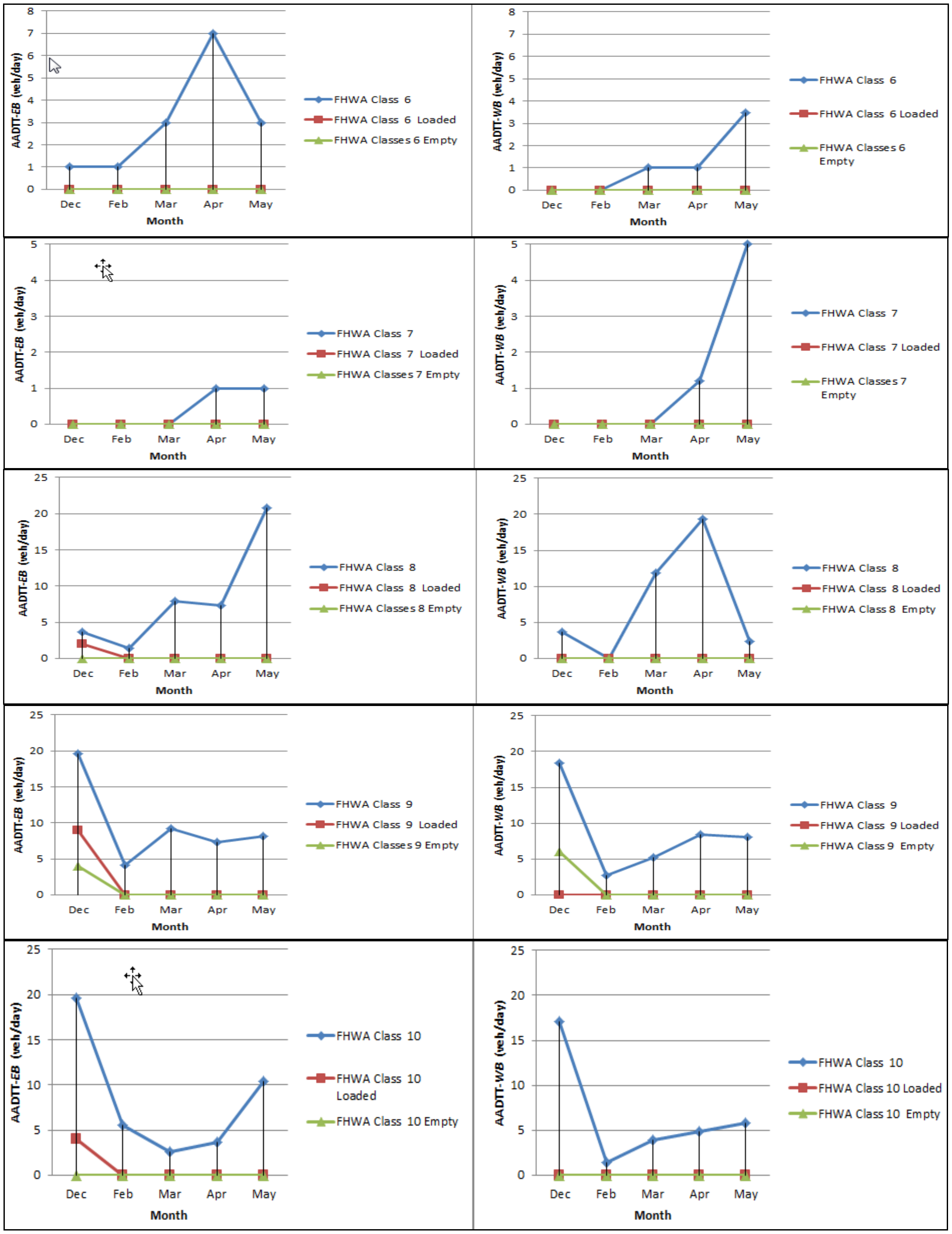


Figure 6.17 FHWA Vehicle Class Directional Volume Variations for STH 48 Coverage Station at Weirgor

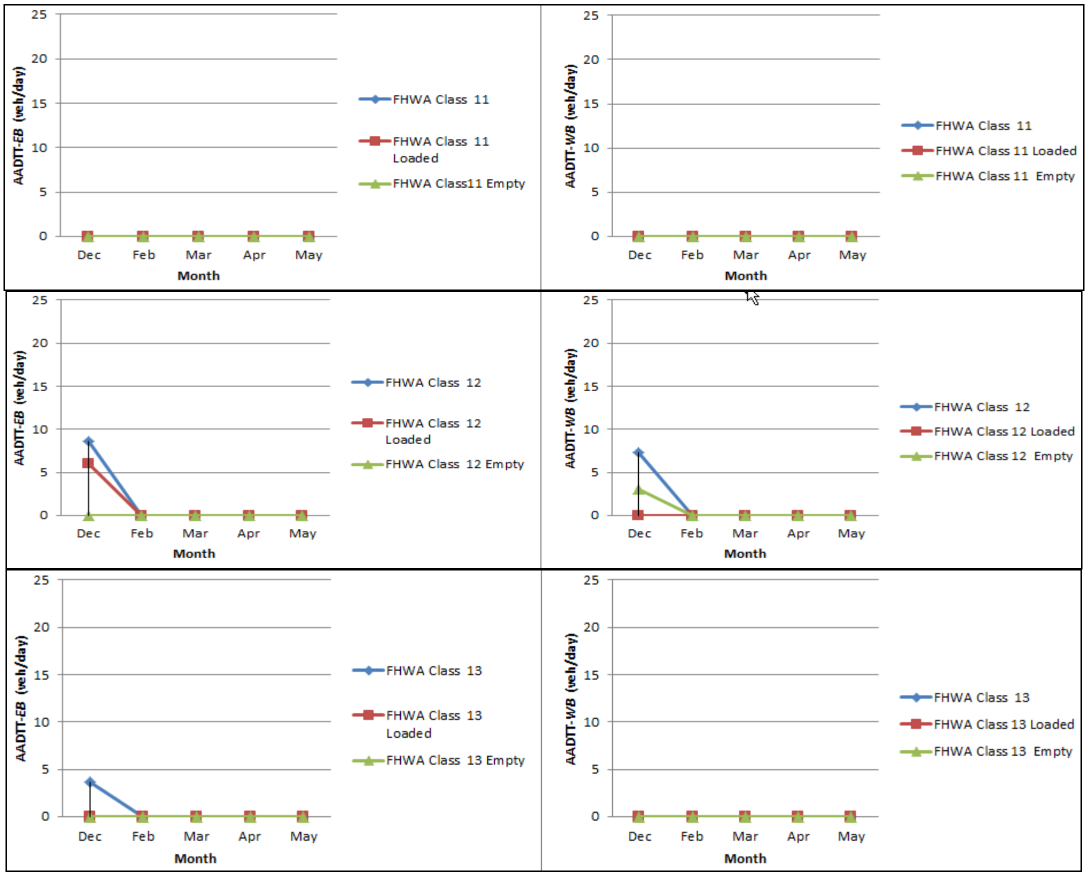


Figure 6.17 (Cont.)

6.2.6 STH 40 in Radisson

The STH 40 coverage station was set up north of the Couderay River bridge in the Village of Radisson (see Figure 6.18). Loaded logging truck movement occurred only in the NB direction during the entire study period (see Figure 6.19). The peak loading occurred in December with an AADTT of six trucks per day. No loading movements were observed for any other months except January and March, each of which attracted three trucks per day. Empty logging truck volumes for the NB were low and varied considerably during the study period. The SB attracted a high empty volume of 26 trucks per day for December and no more for the remainder of the study period.

The vehicle class-by-class observations shown in Figure 6.20 indicate that all December loadings were carried by class 9 trucks, while January and March loadings were carried by class 10 and class 6, respectively. With the exception of classes 7, 10, and 11, empty logging trucks representing all other classes were observed.

Figure 6.18 STH 40 Coverage Station Location at Radisson

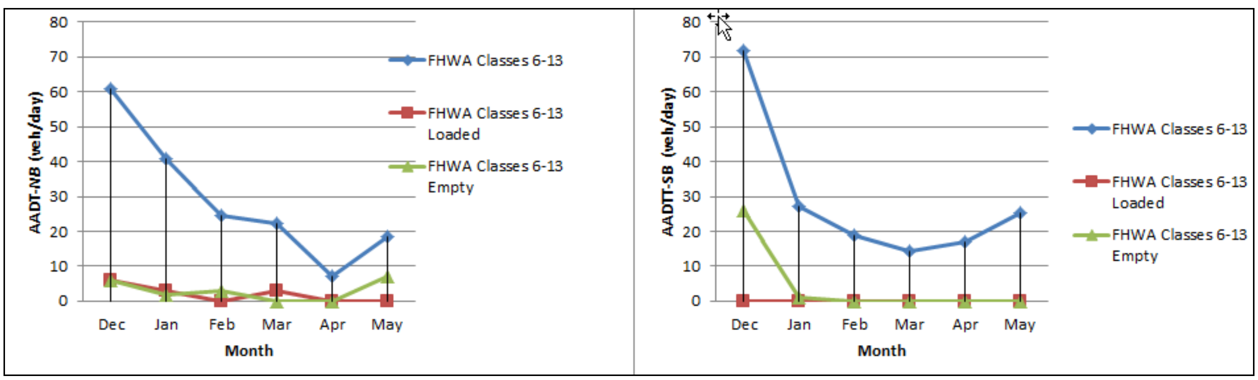


Figure 6.19 Combined FHWA Classes 6-13 AADTT Variations for STH 40 at Radisson

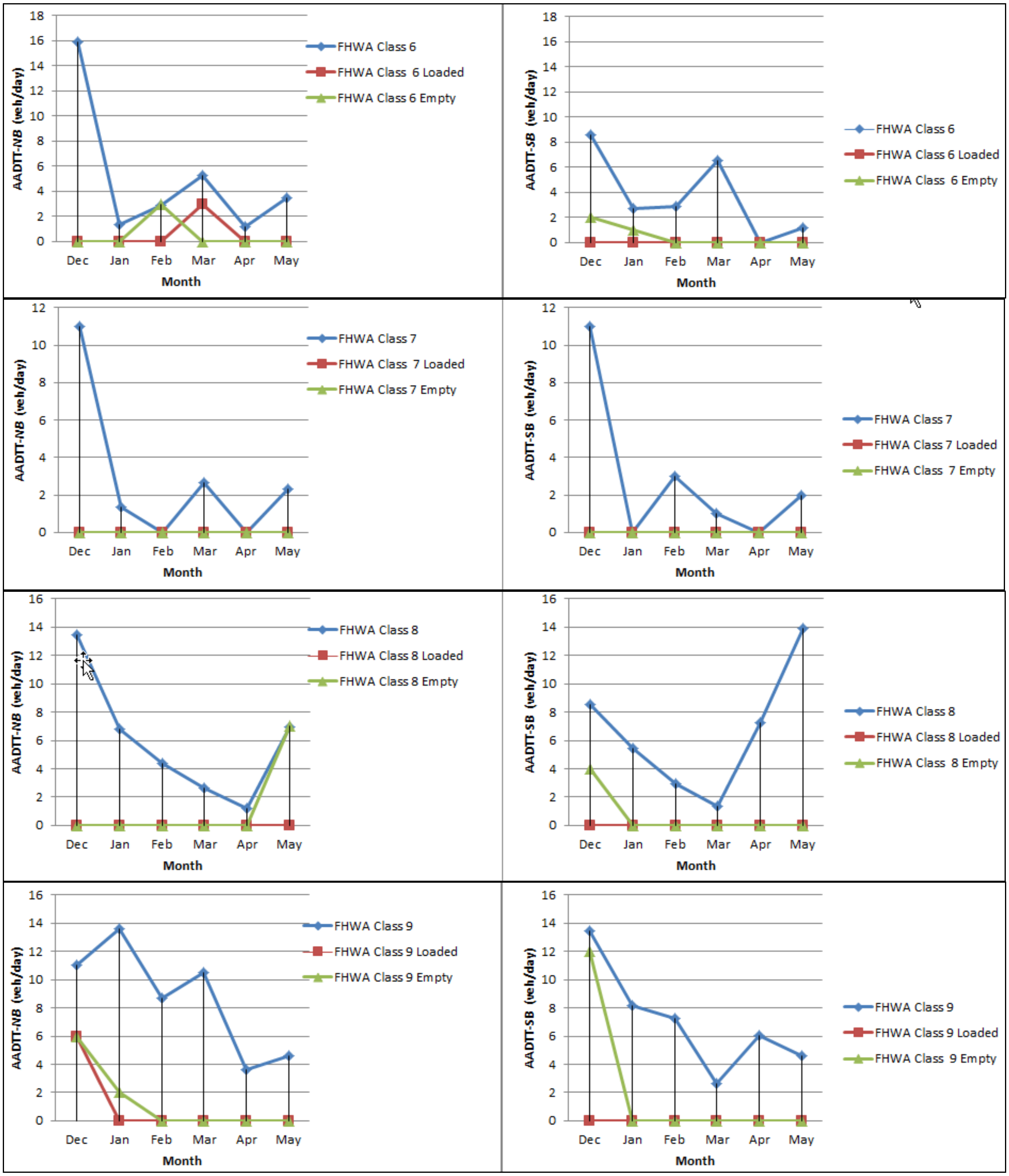


Figure 6.20 FHWA Vehicle Class Directional Volume Variations for STH 40 Coverage Station at Radisson

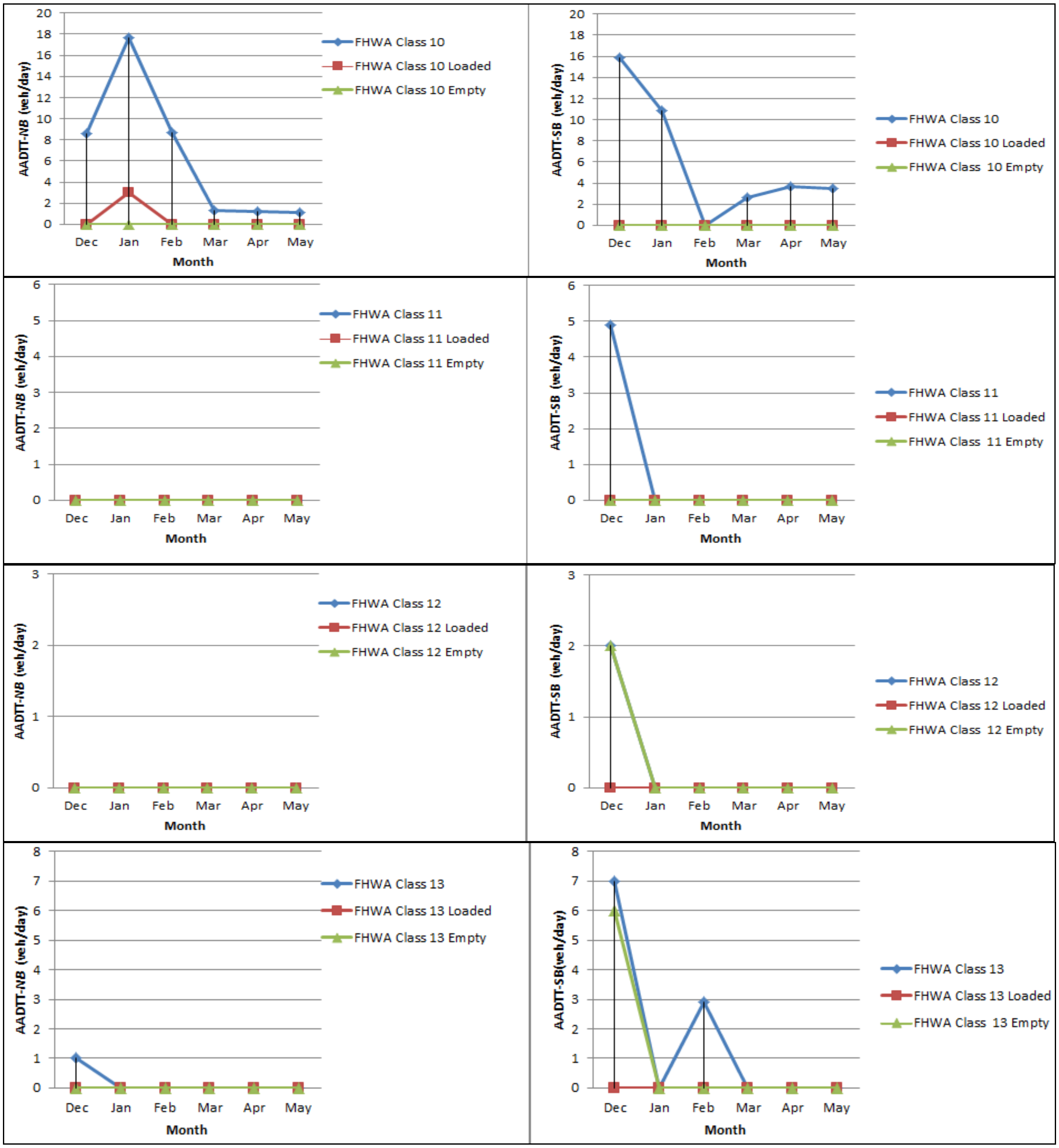


Figure 6.20 (Cont.)

6.2.7 STH 40 in Rusk County

The coverage count on STH 40 south of W. County Line Rd was set up just east of the Canadian National Railway line and north of N. Star Rd (see Figure 6.21). The largest combined log loaded truck volume (13 trucks/day) was recorded in December only for the SB direction. The NB direction had 3 trucks/day but only for February (see Figure 6.22).

The truck class-by-class observations in Figure 6.23 reveal that only class 10 trucks carried logs in the NB direction but only for February, at a rate of 3 trucks/day. For the SB direction, classes 8 and 9 carried logs at a combined rate of 13 trucks/day, with class 9 carrying 85% (11/13) of the volume per day. Class 12 empty trucks were observed for the SB direction but for February only at a rate of 3 trucks/day. There were no other empty truck movements during the entire study period.

Figure 6.21 STH 40 Coverage Station South of W County Line Rd

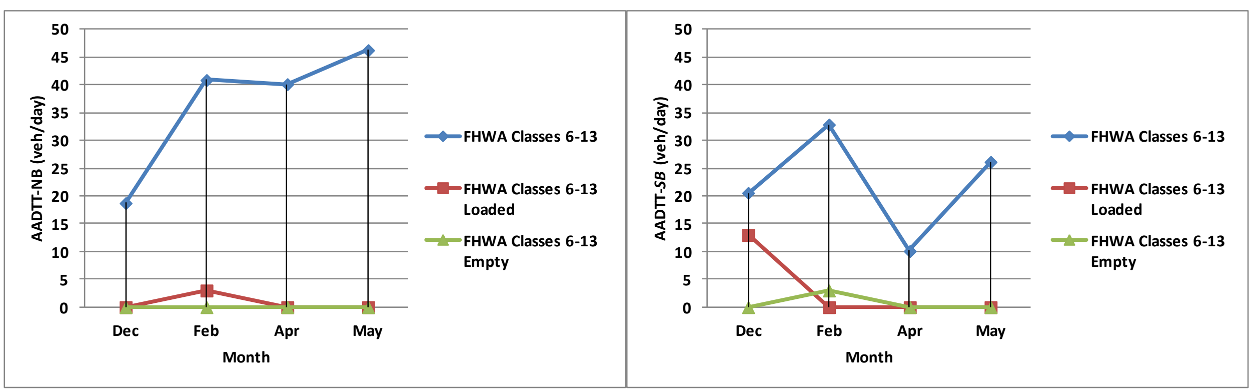


Figure 6.22 Combined FHWA Classes 6-13 AADTT Variations for STH 40 South of W County Line Rd

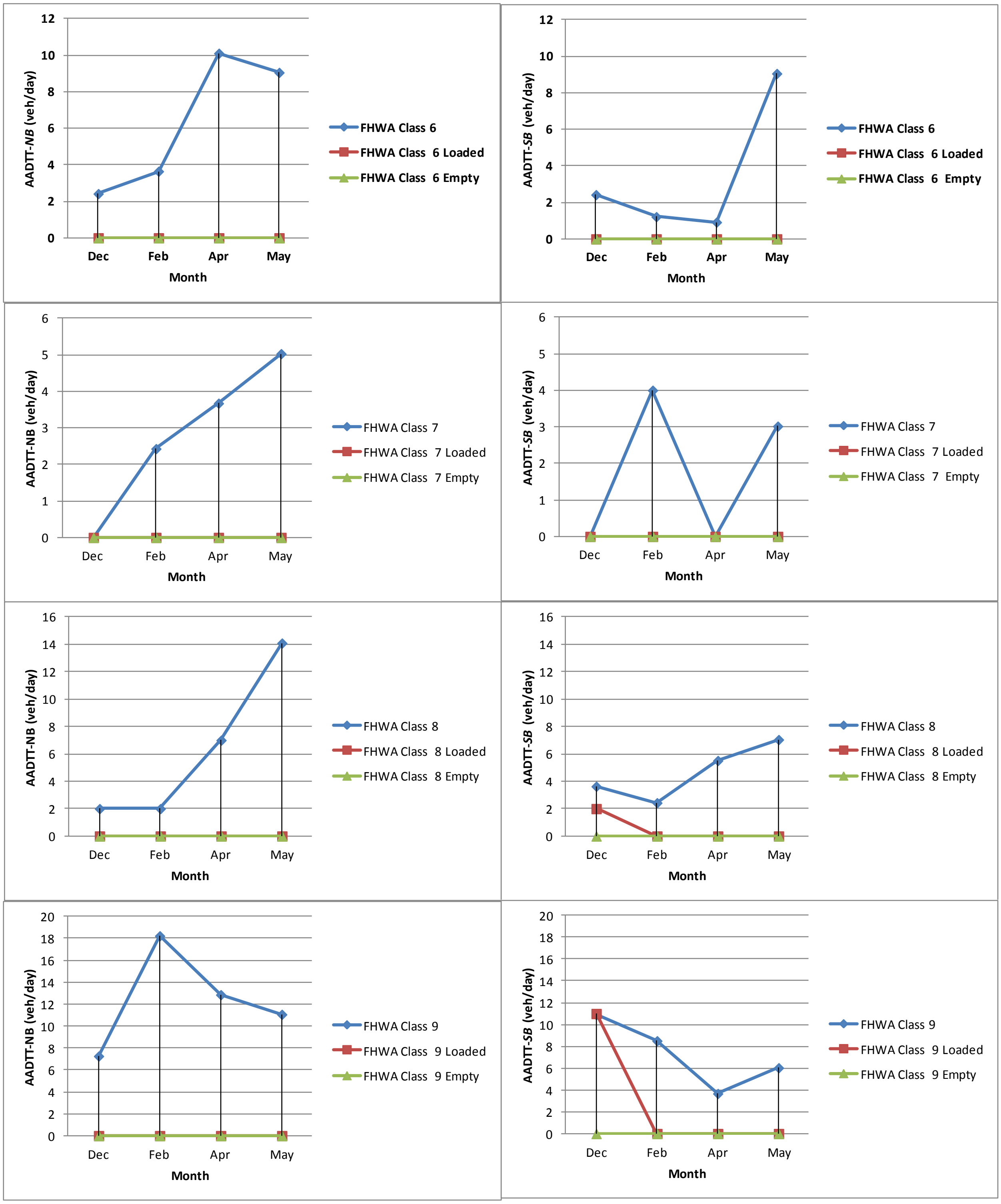


Figure 6.23 FHWA Vehicle Class Directional Volume Variations for STH 40 South of W. County Line Rd

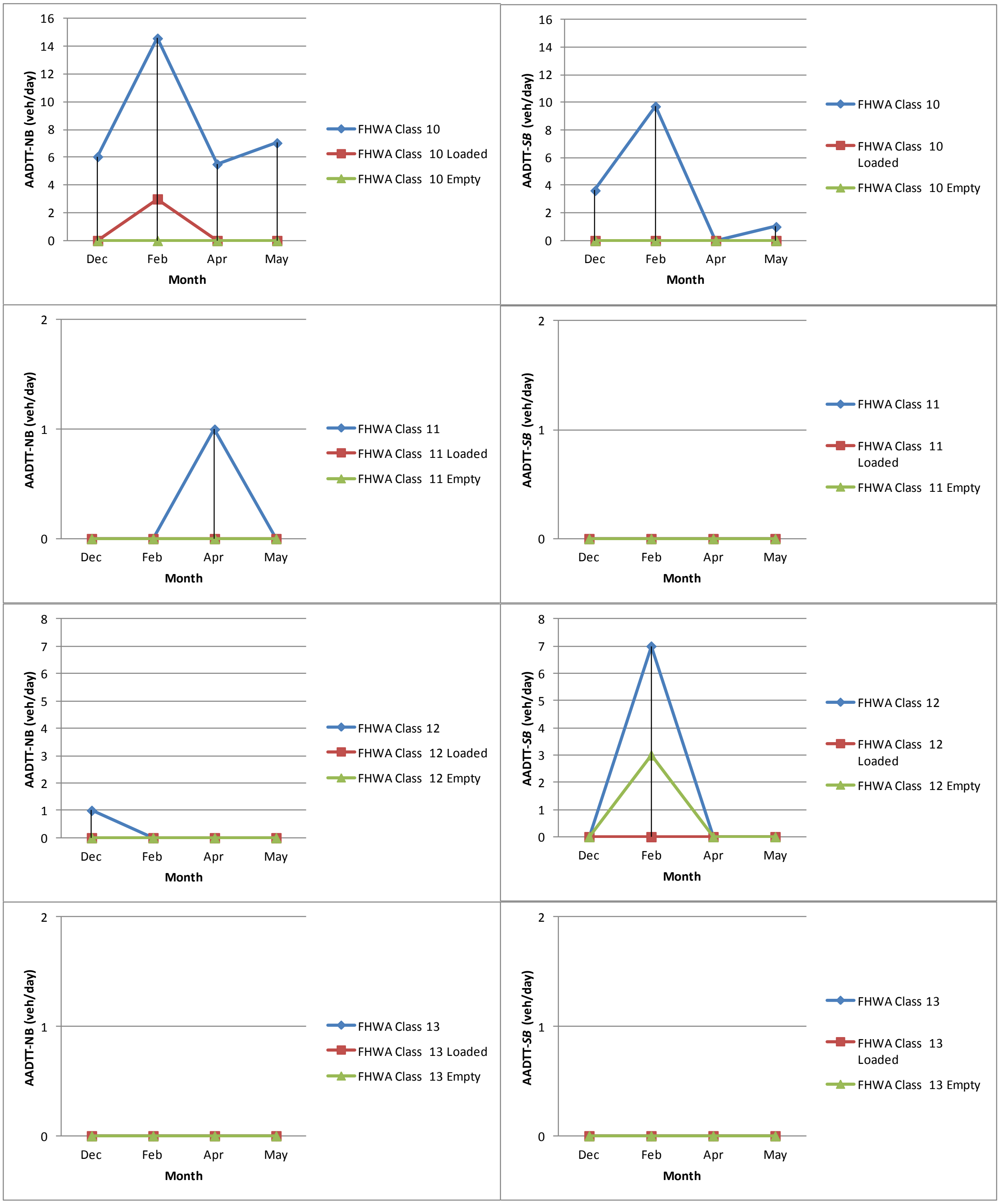


Figure 6.23 (Cont.)

A summary of logging truck volume variation patterns for all project segments is presented in Table 6.9.

Table 6.9 Summary of Logging Truck Volume Variation Patterns

Traffic Count Location	Project Limits Impacted	Volume Characteristics
STH 27 at Hayward	STH 70-Hayward	• There were more trucks loaded with logs in the winter (Dec. 2011-Feb. 2012) than in spring (March-May) in the NB direction with the peak occurring in February. • The number of loaded logging trucks in February in the NB direction was approximately eight times that in the SB direction. The total empty logging truck volume in the SB direction was about double that in the NB direction. • Logs were predominantly carried by FHWA truck classes 9 and 10. The two vehicle classes carried nearly 100% (61/63) of all the log truck volume per day in the NB direction during the peak month. In the SB direction, the peak period occurred in January and the two vehicle classes again carried nearly 100% (13/14) of all log truck volume per day. In March, the loaded truck volume in the NB direction dropped to 4 trucks/day.
STH 77, West of Brooklyn Rd., Minong	CTH H to USH 53	• Loaded truck movements occurred only in the EB direction from January to May, while empty truck movements occurred only in the WB direction for the same period. • Peak loading occurred in February and April at a rate of 32 trucks/day while the minimum loading volume occurred in March and May. The peak for empty logging trucks occurred in February with the minimum occurring in March. • FHWA classes 9 and 10 were the main carriers of logs. Class 9 carried more logs during the peak month of February compared to class 10.
STH 77 at Canadian National Railway (CNR) bridge crossing	Minong USH 53 to CTH M	• Peak loading occurred in January for both directions but with higher volume of 51 trucks/day in the EB direction compared to 28 trucks/day for the WB. • Loading activity stopped in March for the WB direction but continued throughout the entire study period for the EB, which registered a minimum of 19 trucks/day. • FHWA vehicle classes 9 and 10 were the main carriers of logs predominantly in the EB direction. Vehicle class 10, however, transported more logs per day throughout the study period.
STH 27/70 at Radisson	Radisson to Ojibwa	• There were twice as many loaded trucks in the EB direction than in the WB direction during the study period. During the same period however, there were more empty trucks in the WB direction than in the EB direction. The EB loading peaked in December at a rate of 54 trucks/day with FHWA classes 9 and 10 carrying 87% of the volume. The WB loading peaked in February at a rate of 32 trucks/day.

Table 6.9 (Cont.)

STH 27 at the Thornapple River Bridge Crossing	Ojibwa to Ladysmith	• Loaded logging truck movement was predominantly SB with a peak average of 23 loaded trucks per day in December and February, and then dwindling to 3 per day in March. • February was the only month that loading activity occurred in the NB direction with six loaded trucks per day. Classes 9 and 10 carried nearly 100% of the daily loaded trucks in the SB direction during the study period.
STH 48 east of Canadian National Railway line in Wiergor	West County Line to STH 40/CTH D	• Loaded logging truck activity occurred in the EB direction for December only, averaging 21 trucks per day. No loaded logging truck activity occurred in the WB direction during the entire study period. • Empty logging trucks were observed in both directions for December only with the higher volume (9 trucks per day) occuring in the WB direction. • Classes 8, 9, 10, and 12 were carriers of logs in the EB direction in December. Class 9 carried the largest share at nine trucks/day followed by class 12 with six daily trucks. • Empty logging truck traffic was dominated by class 9 in both directions.
STH 40 South of W County Line Road	Becky Creek to North County Line	• The largest combined loaded truck volume (13 trucks/day) was recorded in December but for the SB direction only. The NB direction had 3 trucks/day but only for February. • Class 10 trucks carried logs in the NB direction but only for February, at a rate of 3 trucks/day. For the SB direction, classes 8 and 9 carried logs at a combined rate of 13 trucks/day, with class 9 carrying 85% (11/13) of the volume. • There were no empty truck movements during the entire study period except February but for the SB direction only.
STH 40 at Couderay River bridge in Radisson	STH 48 to STH 27/70 Radisson	• Loaded logging truck movement occurred only in the NB direction during the entire study period with peak loading (six trucks/day) occurring in December. • Empty logging truck volumes for the NB varied considerably during the study period. The SB attracted a high empty volume of 26 trucks per day for December and no more for the remainder of the study period. • All December loadings were carried by class 9 trucks, while January and March loadings were carried by classes 10 and 6, respectively. March loading was 3 trucks/day.

6.3 Log Truck Weight

Log truck weight data were collected from platform scales at the entry to log destinations in the vicinity of the 11 highway segments evaluated in this study. Individual axle weight and axle spacing data were collected monthly before and after the spring thaw suspension period at four weigh scales in the study region. The purpose of collecting this data was to measure and report the actual axle load distribution for various truck axle configurations to examine their potential effect on pavement performance as discussed in the following chapter.

The results of the previous traffic count analysis indicated that FHWA classes 9 and 10 are the main carriers of logs throughout the studied network. This observation was confirmed as the study moved to the truck weight phase at the platform scales. FHWA classes 6, 7, 8, 11, and 12 were also observed but at a much lesser frequency than classes 9 and 10. Figure 6.24 provides photos of the FHWA class 7 and 9 trucks, and two FHWA class 10 truck configurations. Figure 6.24b is the class 9 "18 wheel" semi-truck with variable trailer axle spacing. Figure 6.24c is the class 10 6-axle semi-trailer having a single 3-axle trailer and Figure 6.24d is the class 10 6-axle truck with a single 2-axle "pup" trailer.

(a) FHWA Class 7, 4+ axle truck single

(b) FHWA Class 9, 5-axle truck semi

(c) FHWA Class 10, 6-Axle truck semi

(d) FHWA Class 10, 6-axle truck trailer

Figure 6.24 Logging Trucks in FHWA Classes 7, 9 and 10

6.3.1 Individual Axle Weights and Spacings

Individual axle weights were measured using calibrated platform scales and axle spacing was recorded using a measuring wheel. Cumulative axle weights were recorded as successive axles occupied the platform scale, then a back-calculation procedure determined the individual axle weights. Figure 6.25 illustrates these measurements at a platform scale.

Figure 6.25 Measurement of Individual Axle Weight and Spacing on Platform Scale

The axle spacing was used to determine the axle group type as defined by AASHTO (2001) as follows:

- A *single axle* is defined as an axle located at a distance greater than 8 ft or at a distance less than 3.33 feet from an adjacent axle.
- A *tandem axle* is defined as two adjacent axles with a spacing of 3.33 to 8 feet.
- A *tridem axle* is defined as three axles with a spacing of less than 12 feet from the first to the third axle.
- A *quad axle* is defined as four axles with a spacing of less than 16 feet from the first to the fourth axle.

Wisconsin has a year-round weight limit of 80,000 lbs gross vehicle weight with special overweight permits and special permits for 5-axle logging trucks up to 90,000 lbs and 6-axle logging trucks up to 98,000 lbs. The maximum allowable load for a single axle is 23,000 lbs on frozen roads, while the allowable load for tandem axles is 38,000 lbs for tandem axles with spacing in the range of 4 to less than 7 feet. Tandem axles with at least 7 feet spacing can carry a maximum allowable load of 46,000 lbs (WisDOT 2011d). In addition, the gross weight imposed on the highway by all axles of a vehicle or combination of vehicles is limited to 98,000 lbs. Tables 6.10 through 6.12 provide the individual axle basic summary statistics for the observed FHWA classes 9 and 10, respectively.

Table 6.10 Axle Spacing and Weights for FHWA Class 9, 5-Axle Semi Truck

Statistic	Axle or vehicle weight, lbs								Axle Spacing, ft			
	Steer	Drive #1	Drive #2	Trailer #1	Trailer #2	GVW	NVW	Log Wt	Steer to Drive #1	Drive #1 to Drive #2	Drive #2 to Trailer #1	Trailer #1 to Trailer #2
(a) Loaded												
Average	12225	15610	17369	19020	18478	82701	32331	50370	17	4	27	7
Std. Dev.	2856	4668	2785	3287	2570	4064	1879	4528	1.5	0.2	2.6	2.5
Maximum	18540	25900	22680	22660	25300	91900	36120	60380	19	4.5	32.5	10.5
Minimum	9030	5660	10300	8160	13230	78060	30860	44070	14	4	24	4
Sample	20	20	20	20	20	20	20	20	20	20	20	20
(b) Empty												
Average	9930	6953.3	6736	4011	4493	32257	32158	0	16	4	28	6
Std. Dev.	609	657	714	573	515	1904	1954	0	1.7	0.2	3.1	1.7
Maximum	10640	8180	7940	5010	5080	35560	35560	0	19	4.5	32.5	8.5
Minimum	8650	6220	6000	3220	3490	30860	30860	0	14	4	24	4
Sample	12	12	12	12	12	12	12	12	12	12	12	12

In Table 6.10, the FHWA class 9 (5-axle semi-trailer) had gross vehicle weights (GVW) ranging from 78,060 lbs to 91,900 lbs, with an average weight of 82,701 lbs. Weight exceeding the year-round weight limit of 80,000 lbs GVW is allowed with a special overweight permit during frozen road declaration allowing logging trucks up to 90,000 lbs. The empty net vehicle weight (NVW) ranged from 30,860 lbs to 35,560 lbs, averaging on the loaded scale at 32,331 lbs and on the empty scale at 32,158 lbs. The reason for the slight difference in averages is not all trucks were weighed for individual axles on both the loaded inbound and empty outbound scale. The averages indicate a NVW about 32,000 lbs allowing a log payload of 48,000 lbs or 58,000 lbs, depending on whether the operator holds a 90,000-lb permit.

Loaded weights of individual axles averaged from 12,225 lbs on the steer axle, to 15,510 lbs and 17,369 lbs on the drive axles, to 19,020 lbs and 18,478 lbs on the trailer axles. The interior drive and trailer axles, on average, carried more weight than the external axles. There were instances where the maximum loaded axle weight exceeded 18,000 lbs with drive axles of 22,680 lbs and 25,900 lbs, and trailer axles of 22,660 lbs and 25,300 lbs. Empty weights of individual axles averaged 9,930 lbs on the steer axles, 6,736 lbs and 6,953 lbs on the drive axles, and 4,011 lbs and 4,493 lbs on the trailer axles. An empty truck had about a 25% reduction in steer axle weight.

The monthly sampled axle load spectra for the loaded trucks are also presented in Figure 6.26, which indicates that none of the FHWA class 9 trucks violated the 23,000-lb limit specified by WisDOT for single axles for frozen roads during the winter (Dec-Feb). During the same period however, 22% (2 out 9) axles violated the 38,000-lbs limit for tandem axles with spacing in the range of 4-7 feet by an average of 570 lbs. Per Wisconsin Statute s.348.15(br), the single axle load is limited to 21,500 lbs, while the load on a tandem axle is limited to 37,000-lb any other time of the year for vehicle or combination of vehicles that transport peeled or unpeeled forest products cut crosswise on Class A highways and axle spacing is 8 or less feet. During the spring, 4.5% of axles (1 of 22) were in violation of the single axle load limit by 3,800 lbs. On the tandem axle side, 8.3% of axles (2 of 24) exceeded the 37,000-lb limit by an average of 4,125 lbs.

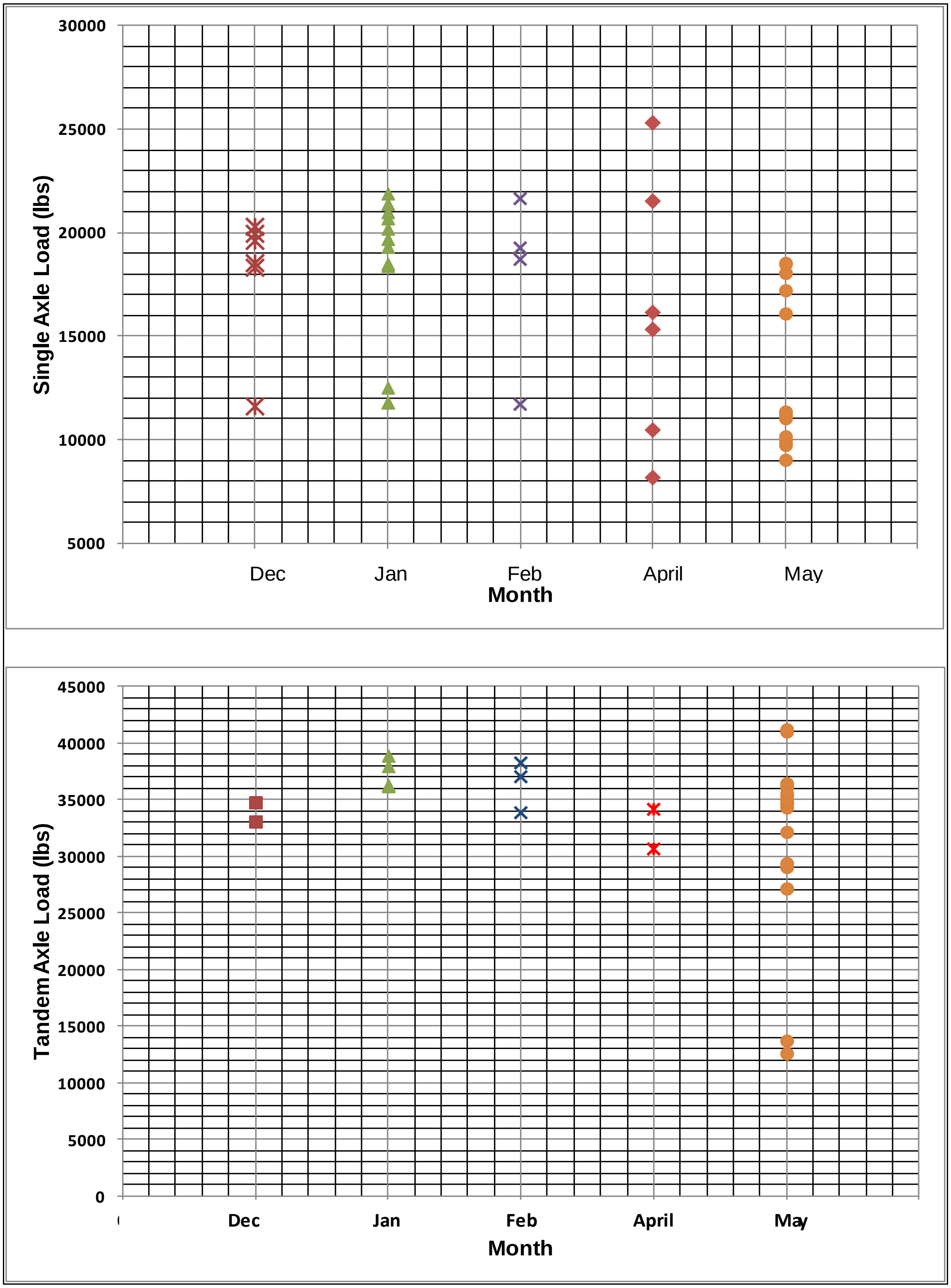


Figure 6.26 Monthly Axle Load Spectra for FHWA Class 9 Sampled Trucks at Platform Scales

Table 6.11 summarizes FHWA class 10, 6-axle semi-trailer, axle weights and spacing. Gross vehicle weights (GVW) ranged from 87,480 lbs to 100,880 lbs, with an average weight of 96,376 lbs. As previously stated, a GVW of 98,000 lbs is allowed with a special overweight RS permit. Thus, the average GVW of the 45-truck sample size was below the 98,000-lb limit. The empty new vehicle weight (NVW) ranged from 32,000 lbs to 41,760 lbs, averaging 37,775 lbs on the loaded scale. Log payload ranged from 49,840 lbs to 63,600 lbs.

Table 6.11 Axle Spacing and Weights for FHWA Class 10, 6-Axle Semi Truck

	Axle or vehicle weight, lbs									Axle Spacing, ft				
Statistic	Steer	Drive #1	Drive #2	Trailer #1	Trailer #2	Trailer #3	GVW	NVW	Log Wt	Steer to Drive #1	Drive #1 to Drive #2	Drive #2 to Trailer #1	Trailer #1 to Trailer #2	Trailer #2 to Trailer #3
(a) Loaded														
Average	11938	18001	17393	16188	16085	16771	96376	37775	58600	16	4	26	5	5
Std. Dev.	1163	2558	1644	2244	2640	2290	2353	1911	2310	0.9	0.2	4.9	1.9	2.4
Maximum	18300	33000	21780	19800	24120	23360	100880	41760	63600	19	5.5	29.5	14.5	16.5
Minimum	10120	14300	12040	9140	7880	11940	87480	32000	49840	14.5	4	4.5	4.5	3
Sample	45	45	45	45	45	45	45	45	45	45	45	45	45	45
(b) Empty														
Average	10403	7240	7480	3669	4315	4622	37554	37554	0	16	4	26	5	6
Std. Dev.	771	760	820	724	897	885	2264	2264	0	0.5	0.2	2.3	0.8	1.9
Maximum	11560	9520	8800	5150	5780	6540	41630	41630	0	17	4.5	28.5	6.5	10
Minimum	9020	5970	6370	2530	2690	2840	33540	33540	0	15	4	21	4	4
Sample	21	21	21	20	21	21	21	21	21	21	21	21	21	20

Loaded weights of individual axles averaged from 11,938 lbs on the steer axle, to 18,001 lbs and 17,393 lbs on the drive axles, to the three trailer axles averaging 16,188 lbs, 16,085 lbs, and 16,771 lbs. Unlike the 5-axle semi with 2-axle trailer, the three trailer axles were very similar in average weight. The maximum loaded axle weight exceeded 18,000 lbs with drive axles of 33,000 lbs and 21,780 lbs, and trailer axles of 19,800 lbs, 24,120 lbs, and 23,360 lbs. Empty weights of individual axles averaged 10,403 lbs on the steer axle, 7,240 lbs and 7,480 lbs on the drive axles (about 1,000 lbs heavier than the 5-axle semi), and trailer axles of 3,669 lbs, 4,315 lbs, and 4,622 lbs. An empty truck had about a 15% reduction in steer axle weight.

In Table 6.12, the FHWA class 10, 6-axle truck with a "pup" trailer, had a GVW ranging from 90,100 lbs to 101,420 lbs, with an average weight of 96,598 lbs, which was about 200 lbs heavier than the 6-axle semi-trailer. The empty NVW ranged from 32,340 lbs to 42,420 lbs, averaging 37,998 lbs. Log payload ranged from 54,480 lbs to 63,830 lbs.

Table 6.12 Axle Spacing and Weights for FHWA Class 10, 6-axle Truck with a"Pup" Trailer

Statistic	Axle or vehicle weight, lbs									Axle Spacing, ft				
	Steer	Idler	Drive #1	Drive #2	Trailer #1	Trailer #2	GVW	NVW	Log Wt	Steer to Idler	Idler to Drive #1	Drive #1 to Drive #2	Drive #2 to Trailer #1	Trailer #1 to Trailer #2
(a) Loaded														
Average	17240	10375	17539	16600	17466	17378	96598	37988	58609	18	5	4	15	13
Std. Dev.	1635	3210	2212	2457	1237	1050	3210	2498	2662	0.7	0.6	0.4	3.4	3.7
Maximum	19700	18150	22400	20400	19200	18980	101420	42420	63820	19	5.5	4.5	20.5	16.5
Minimum	12300	5180	12200	12000	14500	14680	90100	32340	54480	17	4	3	12	7.8
Sample	16	16	16	16	16	16	16	16	16	16	16	16	16	16
(b) Empty														
Average	11240	7385	5665	8580	4140	3460	40470	40470	0	14	7	4	13	15
Std. Dev.	1800	1995	275	1320	440	660	1950	1950	0	1.8	1.8	0.0	1.3	1.0
Maximum	13040	9380	5940	9900	4580	4120	42420	42420	0	16	8.5	4	14.5	16
Minimum	9440	5390	5390	7260	3700	2800	38520	38520	0	12.5	5	4	12	14
Sample	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Loaded weights of individual axles averaged from 17,240 lbs on the steer axle (about 5,000 lbs more than the 6-axle semi), to 10,375 lbs on the non-powered idler axle, 17,539 lbs and 16,600 lbs on the drive axles, to the two "pup" trailer axles averaging 17,466 lbs and 17,378 lbs. The maximum loaded axle weight averaged 17,539 lbs and 16,600 lbs on the drive axles, and 19,200 lbs and 18,980 lbs on the trailer axles. There was a small sample of empty truck axle weights with averages of 11,240 lbs on the steer axle (about 1,000 lbs more than the 6-axle semi), 7,385 lbs on the idler axle, 5,665 lbs and 8,580 lbs on the drive axles, and trailer axles of 4,140 lbs and 3,460 lbs. An empty truck had about a 40% reduction in steer axle weight.

The monthly GVW and axle load spectra for all FHWA class 10 measured at the platform scales are further displayed in Figures 6.27 and 6.28, respectively. During the winter (Dec-Feb), 17.5% (7/40) of loaded trucks exceeded the maximum 98,000 lbs GVW limit by an average of 1620 lbs, while 14.6 % (6/41) exceeded the limit by an average of 1643 lbs in the spring (Mar-May). Regarding axle load spectra, no class 10 single-axle load exceeded Wisconsin DOT limits for either frozen or non-frozen road conditions. For tandem axles, approximately 12% (4 of 33 axles) exceeded the 38,000-lb limit for frozen roads by an average of 2,910 lbs during the winter. During the spring, approximately 11% (4 of 36 axles) exceeded the 37,000-lb limit by an average of 565 lbs. Per Wisconsin Statute 348.175, the allowable load limit for tridem axles with spacing in the range of 9-10 feet corresponds to a load range of 55,000 lbs-55,500 lbs for frozen Class A highways. None of the observed loads violated the tridem axle load limit during the winter months. Wisconsin Statute, s.348.15(br) indicates that for groups of three or more consecutive axles more than 9 feet apart, an additional 4,000 lbs is usually allowed during any other time of the year (depending on the distance between foremost and rearmost axles in a group). The observed tridem axle spacing was 10 feet, which corresponds to a load of 47,500 lbs. Approximately 37% (13/35) tridem axles were in violation of the specified limit.

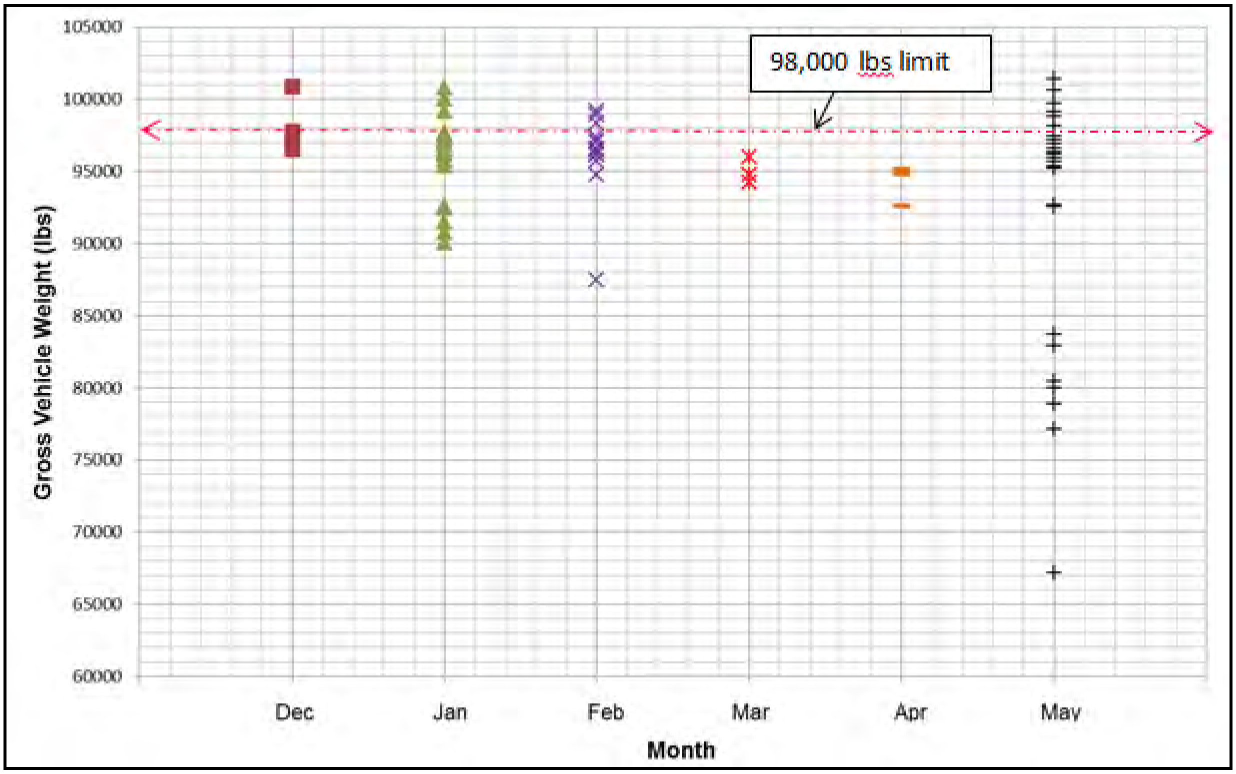


Figure 6.27 Loaded FHWA Class 10 Monthly Gross Vehicle Weight Distribution at Platform Scales

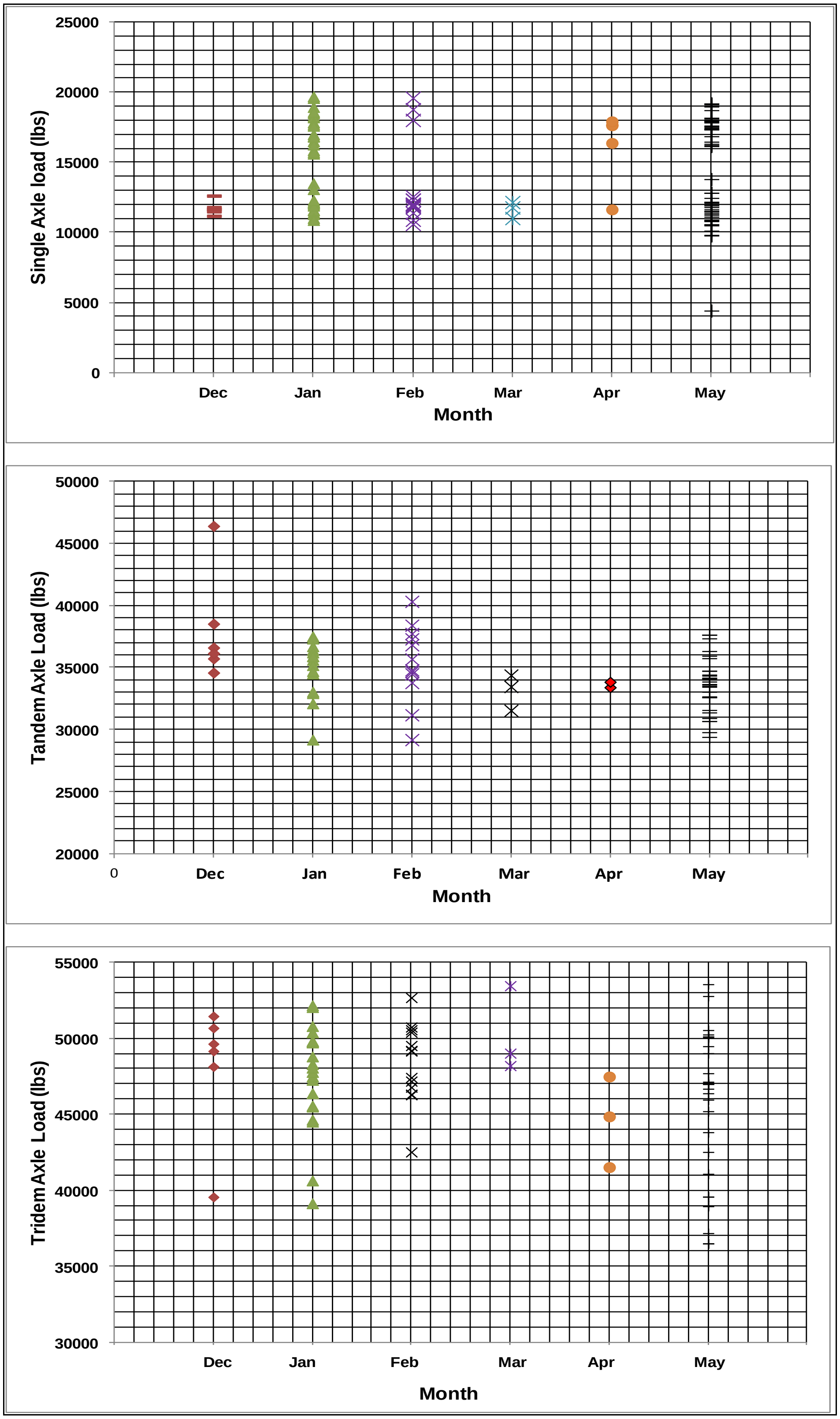


Figure 6.28 Monthly Axle Load Spectra for Sampled FHWA class 10 Trucks at Platform Scales

6.3.2 Monthly Logging Truck Weight Reports

In addition to the data obtained by the research team, operators of two scales in the vicinity of the study area provided monthly weight reports for log trucks that entered and exited the wood yard. To protect the identity of the scale operators, data are reported for the two locations as Scale #1 and Scale #2. Data from the monthly reports included Gross Vehicle Weight (GVW), Empty or Net Vehicle Weight (EVW or NVW), log payload weight, and date. These reports were generated electronically, while other scales considered and not selected for the study used a paper ticket format and manual data entry. It was not possible to control the data fields and input from the two scale operators. Scale #1 had data fields that did not distinguish between 5-axle and 6-axle trucks (FHWA classes 9 and 10). Scale #2 distinguished between FHWA classes but only retained GVW equal or greater than 90,000 lbs.

Table 6.13 presents summary statistics from Scale #1 where all logging trucks entering and exiting the scale were recorded. As mentioned, there was not a data field distinguishing between FWHA classes 9 and 10. Summary statistics are reported monthly for total trucks, maximum and minimum weight, average, standard deviation, and percent of trucks over 98,000 lbs. March 2012 was also divided into the time period before and after the March 9, 2012, spring thaw suspension declaration. The greatest number of trucks was in January with 359 trucks, followed by February at 287 trucks, and May at 275 trucks. There were a total of 220 trucks during the spring thaw declaration month of March, with 197 trucks before the March 9th declaration and 23 trucks after the declaration. In discussions with the truck drivers, many of the county roads imposed weight restrictions on March 9th impeding the efficient flow of logs to the scale. The percentage of trucks over the 98,000-lb limit ranged from 21% in December to 34% in May.

Table 6.13 Monthly Logging Reports from Scale #1

Statistic	Month							
	December 2011	January 2012	February 2012	March 2012	March 1-9, 2012	March 10-31, 2012	April 2012	May 2012
Average, lbs	93711	91321	89804	93253	93337	92534	94603	94756
Std. Dev., lbs	5928	13409	17481	11707	12208	5827	5813	7611
Maximum, lbs	102600	105040	109400	108520	108520	99320	102460	105780
Minimum, lbs	64840	24740	23960	25900	25900	75660	61960	45040
Sample, n	128	359	287	220	197	23	115	275
Sample over 98,000 lbs, n	27	87	82	81	79	2	31	94
Sample over 98,000 lbs, %	21%	24%	29%	37%	40%	9%	27%	34%

Table 6.14 provides summary statistics from Scale #2 where only logging trucks over 90,000 lbs are reported. Data for both 5-axle and 6-axle trucks are reported separately. Summary statistics are reported monthly for total trucks, maximum and minimum weight (over 90,000 lbs), average, standard deviation, and percent of trucks over 98,000 lbs. March 2012 was also subdivided into time periods before and after the March 9, 2012, spring thaw suspension declaration. Similar to Scale #1, the greatest number of trucks at Scale #2 was in January with 444 5-axle trucks and 888 6-axle trucks. The least number of trucks for both axle configurations was in April. During the month of March immediately after the Spring Thaw declaration on March 9th, there were no 5-axle trucks and the number of 6-axle trucks dropped to 40. By

comparison, there were 317 6-axle trucks during the start of March during the frozen road declaration period. Thus, even though 98,000-lb 6-axle log loads are allowed during spring thaw, there is a substantial drop in the number of logging trucks primarily due to restrictions on local roads, such as at the county and township level. The percentage of trucks over the 98,000-lb limit ranged from 21% in April to 35% in January.

Table 6.14 Monthly Logging Reports from Scale #2

Statistic	Month							
	December 2011	January 2012	February 2012	March 2012	March 1-9, 2012	March 10-31, 2012	April 2012	May 2012
(a) FHWA Class 9, 5-axle truck								
Average, lbs	91740	93405	94943	94985	94985	None	94812	93629
Std. Dev., lbs	1276	2714	2723	2823	2823	None	2668	2938
Maximum, lbs	95660	105040	104200	103220	103220	None	103360	104940
Minimum, lbs	90060	90000	90000	90000	90000	None	90080	90000
Sample, n	113	444	536	265	265	None	100	101
(b) FHWA Class 10, 6-axle truck								
Average, lbs	96685	96881	96719	96382	96957	94984	96007	96522
Std. Dev., lbs	2514	2576	2460	2782	2682	2512	2553	2540
Maximum, lbs	105880	105900	108640	107660	107660	102900	108640	107360
Minimum, lbs	90000	90000	90000	90040	90080	90040	90000	90000
Sample, n	1257	2564	2550	1256	890	366	1386	1261
Sample over 98,000 lbs, n	368	888	757	357	317	40	294	341
Sample over 98,000 lbs, %	29%	35%	30%	28%	36%	11%	21%	27%

6.3.3 Traffic Loading Estimates

The primary objective in load estimation was to examine truck impact on pavement performance. It was concluded from the previous traffic analysis that FHWA classes 9 and 10 are the main carriers of logs throughout the studied network. Hence, the effects of these two particular vehicles were examined.

The first step involved the computation of load equivalency factors (LEF) for the various axle loads and configurations. Equivalent loading is a means of equating the pavement damage effect of traffic loading caused by different axle configurations carrying different weights. Using 1993 AASHTO design guide procedures, the varying configurations and loadings can be equated to the damage caused by an 18,000-lb single axle having dual tires on each side by means of a load equivalency factor (LEF). The LEF of any axle is defined as the ratio of the damage per pass of the axle in question to the damage per pass of a standard load, usually the 18,000-lb single axle (Huang 2004). For any given axle load and type (single, tandem, tridem, quad), various LEFs can be calculated for any range of structural capacities. A summation of the LEFs for various axle configurations is given in terms of the number of equivalent single-axle loads (ESALs).

Although LEFs provide a means of expressing equivalent levels of damage between axles, expressing that damage in terms of the average amount of damage inflicted by a particular vehicle is more convenient.

The LEF from each axle on a vehicle can be added together and expressed as the total amount of damage from one pass of that vehicle. This is referred to as a vehicle ESAL factor, which represents the average number of ESAL applications per vehicle. Once ESAL factors have been determined they can be used to convert AADTT to total ESALs for a given pavement structure.

ESAL factors can be calculated by converting the weights measured from the platform scales to LEFs and then to ESALs per vehicle. For flexible pavements, the LEF is based on the axle weights of the axle group and the structural number (SN) and terminal serviceability of the pavement. Huang (2004) presents the following AASHTO equations to calculate the LEF:

$$\log\left(\frac{W_{tx}}{W_{t18}}\right) = 4.79\log(18+1) - 4.79\log(L_X + L_2) + 4.33\log L_2 + \frac{G_t}{\beta_X} - \frac{G_t}{\beta_{18}} \quad (6.6)$$

$$G_t = \log\left(\frac{4.2-\rho_t}{4.2-1.5}\right) \quad (6.7)$$

$$\beta_X = 0.40 + \frac{0.081(L_X + L_2)^{3.23}}{(SN+1)^{5.19} L_2^{3.23}} \quad (6.8)$$

Where,

W_{tX} = number of X-axle load applications at end of time t;
W_{t18} = number of 18-kip single load applications to time t;
L_X = load in kips on one single axle, one set of tandem axles, or one set of tridem axles;
L_2 = axle code (1 for single axle, 2 for tandem axles, 3 for tridem axles, and 4 for quad axles);
B_{18} = value of β_X when L_X =18 and L_2=1; and
$_{Pt}$ = terminal serviceability.

Equation 6.6 is used to solve for (W_{t18}/W_{tx}), which is the LEF for one axle group. The sum of LEFs for each of the axle groups on a specific vehicle gives an ESAL for that vehicle. Equations 6.7 and 6.8 use the terminal serviceability (pt) and SN of the pavement for input into Equation 6.6 to determine the LEF. Although it is important to use accurate inputs with the equation, the terminal serviceability and SN have a relatively small effect on the calculated LEF compared to the axle group weight or type.

In this study, an alternative method based on a generalized fourth-power law developed by Deacon (1969) was used in approximating the LEFs for the various axle groups. The LEF can be estimated by equations 6.9 and 6.10 as follows:

$$LEF_X = \left(\frac{L_X}{18}\right)^4 \quad (6.9)$$

$$LEF_X = \left(\frac{L_X}{L_S} \right)^4 \quad (6.10)$$

Where,

L_x = load in kips on a single axle (using only equation 6.9); and
L_s = load in kips on standard tandem or tridem axles (using equation 6.10 with Lx equaling the same number of axles as L_s).

Huang (2004) indicates that LEF is not very sensitive to pavement thickness and that SN = 5 may be used for the majority of cases. Hence, LEF estimates were based on SN = 5. Once the LEFs were calculated for the various axle groups for FHWA vehicle classes 9 and 10, they were added together and divided by the total number of vehicles weighed for each vehicle class. Table 6.15 shows the ESAL factor estimates for vehicle classes that predominantly carry logs in the study area. When loaded, the class 9 value appears to be about 1.23 times that of class 10. When empty, both factors are about the same. The ESAL factor from the combination of empty and loaded trucks also indicates an overall higher factor for the class 9 truck. The higher value may be due to class 9 having one less axle across which the load can be spread when compared to class 10.

Table 6.15 Average ESAL Factors for Logging Trucks

Vehicle Class	ESAL/Truck		
	Loaded	Empty	All trucks (loaded and empty)
FHWA Class 9	3.27	0.13	2.41
FHWA Class 10	2.66	0.15	2.12

Table 6.15 was used to estimate the log load or cargo per ESAL, which is a good indicator of the relative log-carrying efficiency of the FHWA class 9 and 10 truck configurations studied with reference to the pavement damage caused. The log load for FHWA class 9 averaged 50,370 lbs, which results in log cargo per ESAL of 15,404 lbs/ESAL. The log load for FHWA class 10 averaged 58,303 lbs, which yields a load carrying efficiency of 21,918 lbs/ESAL, which is about 1.4 times that of class 9.

In addition, values from Table 6.15 were used in conjunction with estimated AADTT values to determine the ESALs/day for classes 9 and 10 to investigate their impact on performance. This is presented in the following chapter of the report.

Chapter 7 – Pavement Condition Data Analysis

7.1 Introduction

This chapter is oriented towards addressing three specific objectives of this study, which are restated as follows:

- Determine the effect on pavement life, of new policy changes that allow heavier log loads during spring thaw.
- Identify whether certain vehicle classes/categories are more damaging than others, and possibility of lessening the impact of these heavy loads.
- Determine if certain pavements are impacted with increased loads due to policy change.

The following sections summarize the pavement condition data with statistics and data plots. Formal statistical analyses focusing on a series of hypothesis tests that are directly oriented toward the study objectives are also presented.

7.2 Pavement Condition Data

On a monthly basis from December 2011 to May 2012, manual pavement performance measurements were recorded for longitudinal cracking, alligator cracking, and rutting. Before the Frozen Road Declaration and after the Spring Thaw Suspension Period, a semi-automated measure of roughness was recorded for the International Roughness Index (IRI) and rut depth using standardized laser-optical methods. A summary of performance measurements and measurement frequency includes:

(1) Longitudinal cracking in the wheel path – monthly;
(2) Alligator cracking in the wheel path – monthly;
(3) Rutting in the wheel path – monthly; and
(4) Roughness - October 2011, and May and October 2012 only.

There were three or four 500-ft test sections evaluated within each of the 11 highway segments, except Segment #3 having only one test section due to a short segment length of 1 mile. A 500-ft test section was designated in opposing lanes of traffic (i.e., north/south and east/west) for comparing pavement condition for lanes having predominantly loaded logging trucks with those having a majority of empty logging trucks. Truck traffic data presented in the previous chapter designated predominantly loaded and empty lanes.

Within each test section, longitudinal cracking length in the wheel path was totaled, alligator cracking area in the wheel path was totaled, and rutting measurements were averaged for the right and left wheel paths. Ride measurements were recorded for the continuous length of the highway segment, not multiple 500-ft test sections.

Pavement condition was analyzed using four primary approaches, including (a) plots of performance measures on a monthly basis, (b) simple linear regression models, (c) statistical comparison of loaded and empty logging truck lanes, and (d) changes in pavement condition by truck class. The following sections detail these analyses with focus on the project objectives.

7.3 Monthly Plots of Performance Measures

Plots of monthly performance measures for the 11 highway segments are shown in Figures 7.1 through 7.11. Using the bi-directional traffic data, two-lane highways had opposing lanes designated as either "loaded" logging truck lanes or "empty" logging truck lanes. Loaded and empty lanes were determined from the majority percentage of 98,000-lb capacity 6-axle loaded and empty logging trucks in the respective travel lanes. Performance measures for each lane are plotted by month to visually understand the changes. Asphalt mixture design classification is also provided, including Marshall mix designs (LV = Low Volume; MV = Medium Volume) and Superpave mix designs (E-1 for 1 million ESALS in a 20-yr design life). Multiple readings for each month are shown representing multiple measurements within each highway segment (1, 3 or 4). Ride measurements were not recorded for Segments #7 and #11 due to error in scheduling scans of multiple highway segments having the same highway number.

In general, over the performance period, there was either an increase in distresses with time or no change in distresses for primarily new pavements. In addition, the seven Superpave mix design segments ranging in age from 1 to 8 years exhibited low average rut depths (≤ 6 mm) compared to the older Marshall mix design segments (12-19 years old) which had depths ≤ 16.0 mm. There were instances where some segments exhibited a slight decrease in rutting instead of an expected upward trend. Rutting is considered permanent deformation and is expected to increase over time. It is commonly measured when ground conditions are stable, for example, as in a typical summer. This study, however, was conducted during winter and spring when the pavement experiences vertical (both up and down) movement, due to frost. Hence, the anomalies may have been due to this frost action under varying temperature conditions during the short 6-month observation period.

With the exception of segment #5, all the Superpave mix design segments exhibited lower levels of longitudinal cracking compared to the Marshall mix segments. In addition, none of the Superpave mix design segments experienced any alligator cracking, while three of the four Marshall mix segments did. Figure 7.4 shows that the unloaded or empty lane of an older pavement (Segment #4 at age =12 years, Marshall MV-2 mix design) experienced a sudden significant increase in alligator cracking from 100 ft^2 of low severity during the winter months to 850 ft^2 of low and 150 ft^2 of high severity alligator cracking during the spring thaw months. Initial observations in the winter showed the section had a thin layer of sealcoat with less cracking but as time progressed, it became apparent that the sealcoat was originally installed over existing untreated cracks, which then propagated to the surface during the spring thaw.

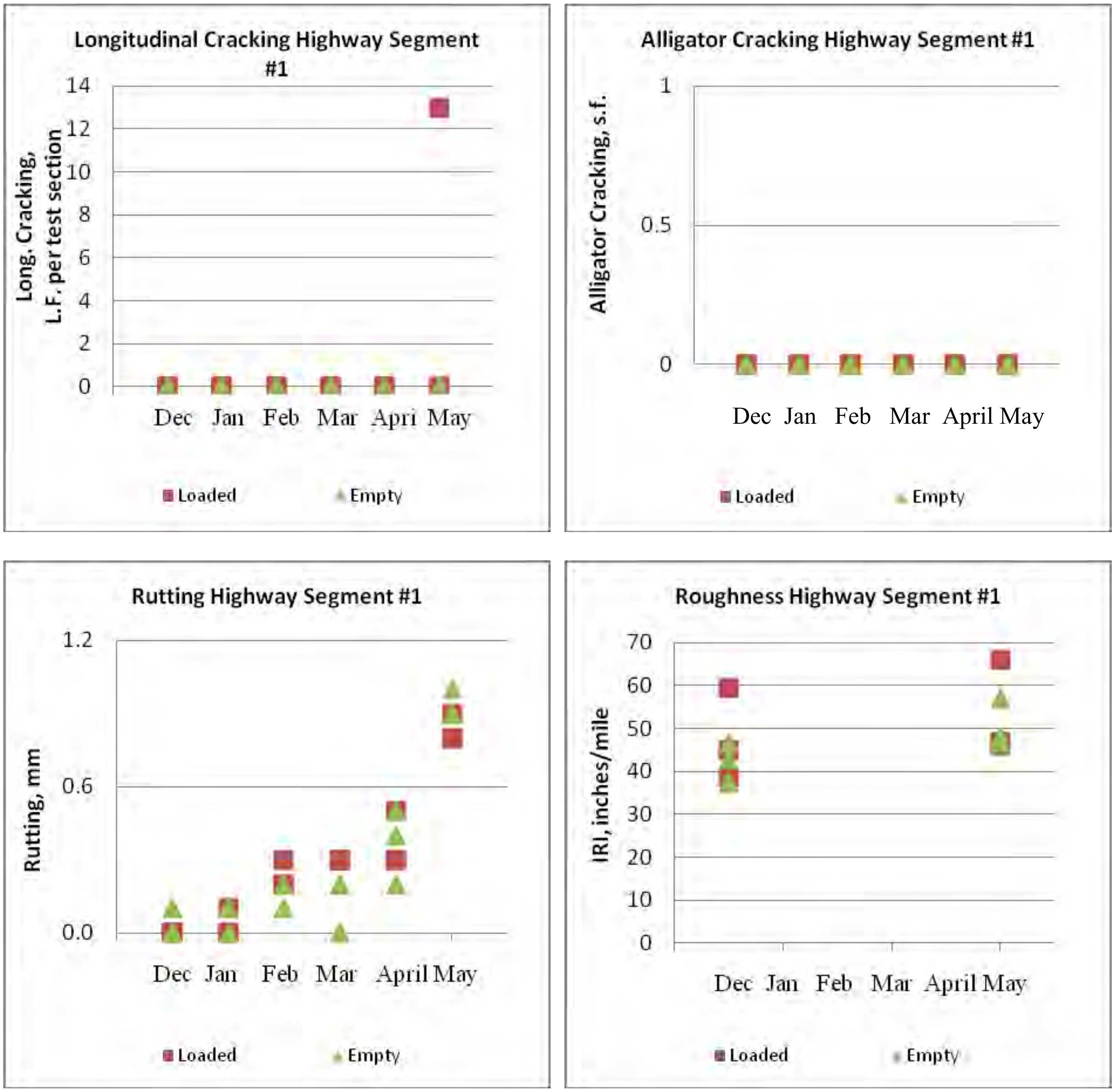


Figure 7.1 Highway Segment #1 Performance, STH 77 Burnett County, Age 1 year, Superpave Warranty E-1

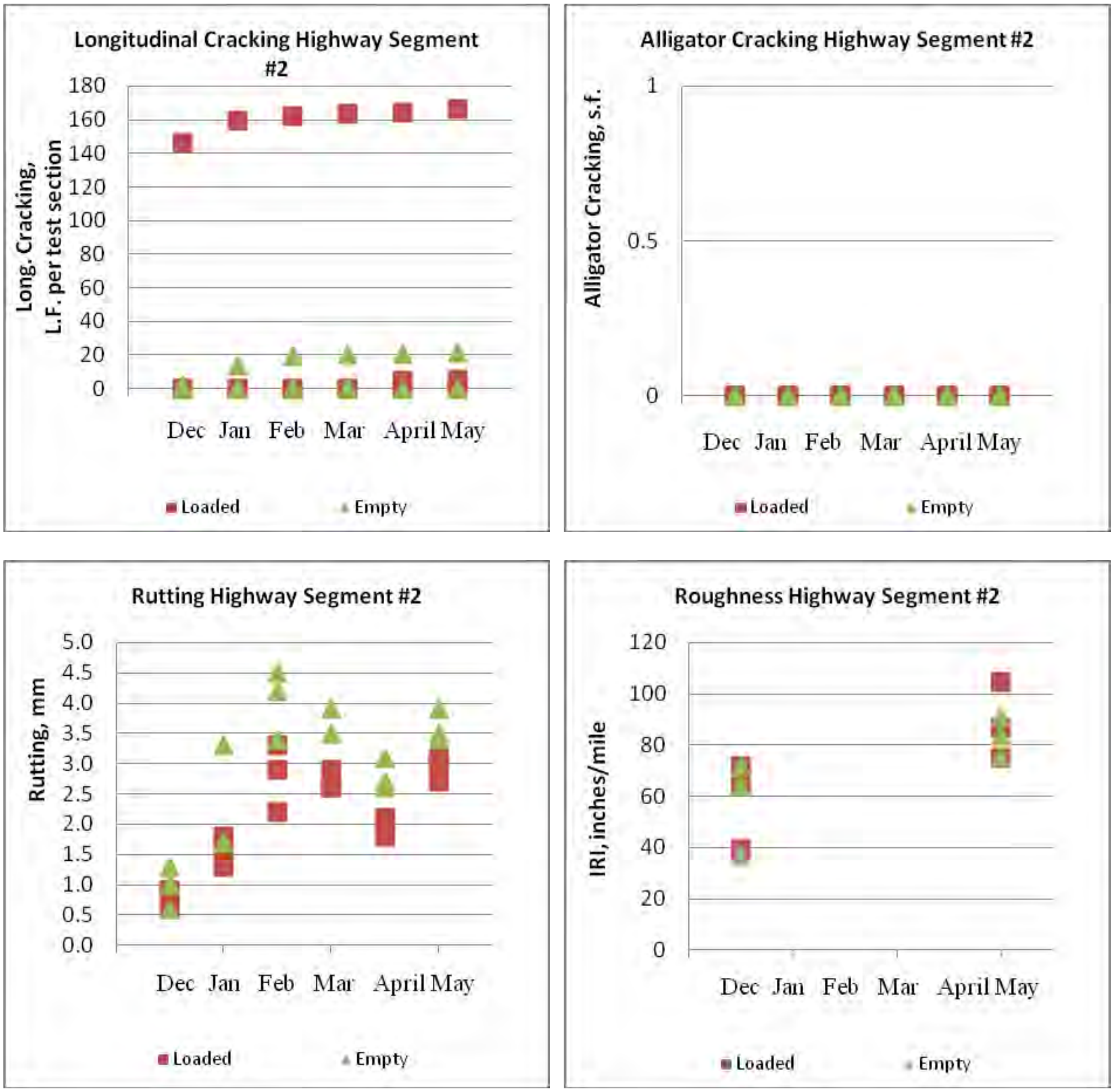


Figure 7.2 Highway Segment #2 Performance, STH 77 Washburn County, Age 7 years, Superpave E-1

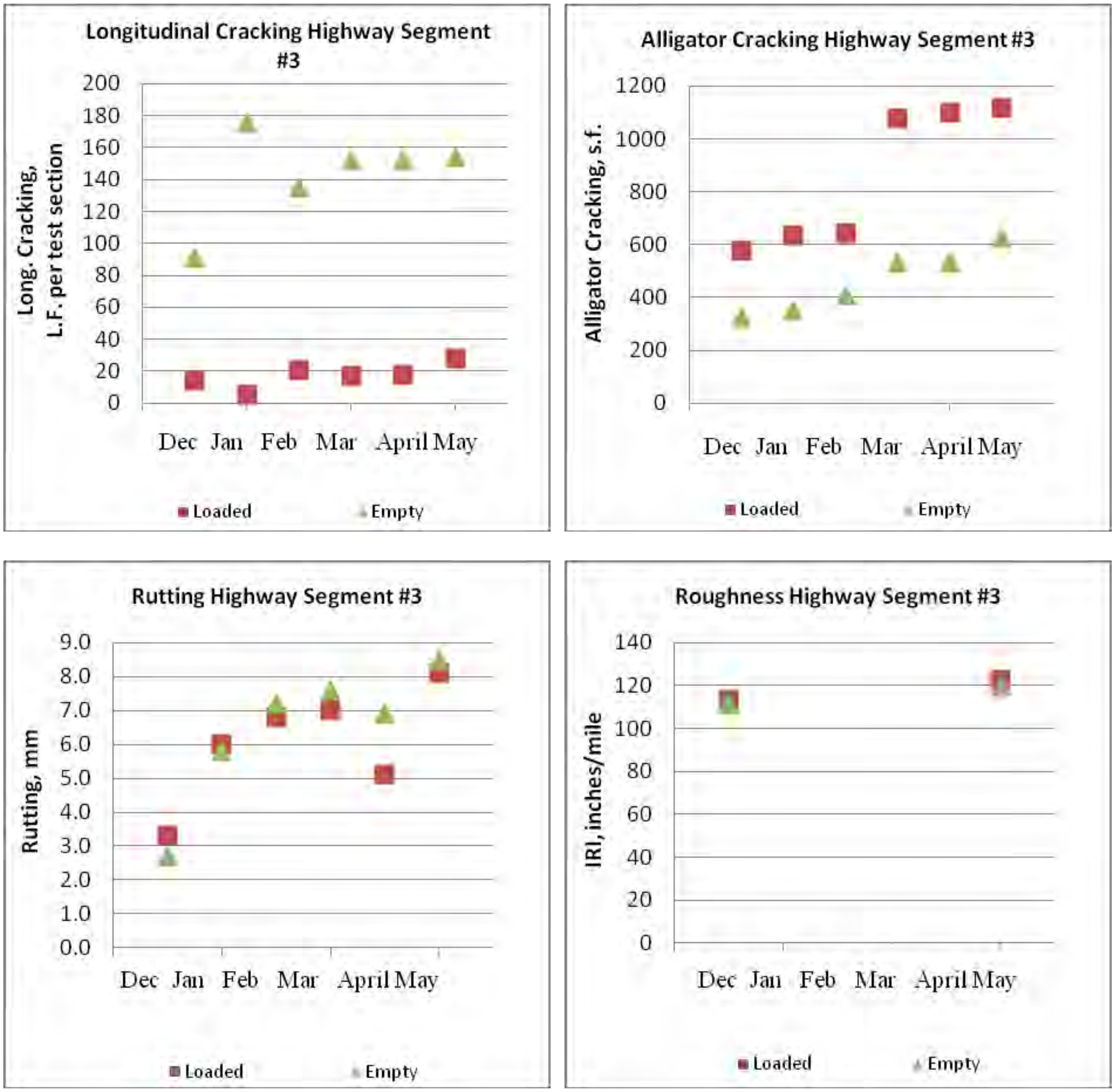


Figure 7.3 Highway Segment #3 Performance, STH 77 Washburn County, Age 13 years, Marshall MV-2

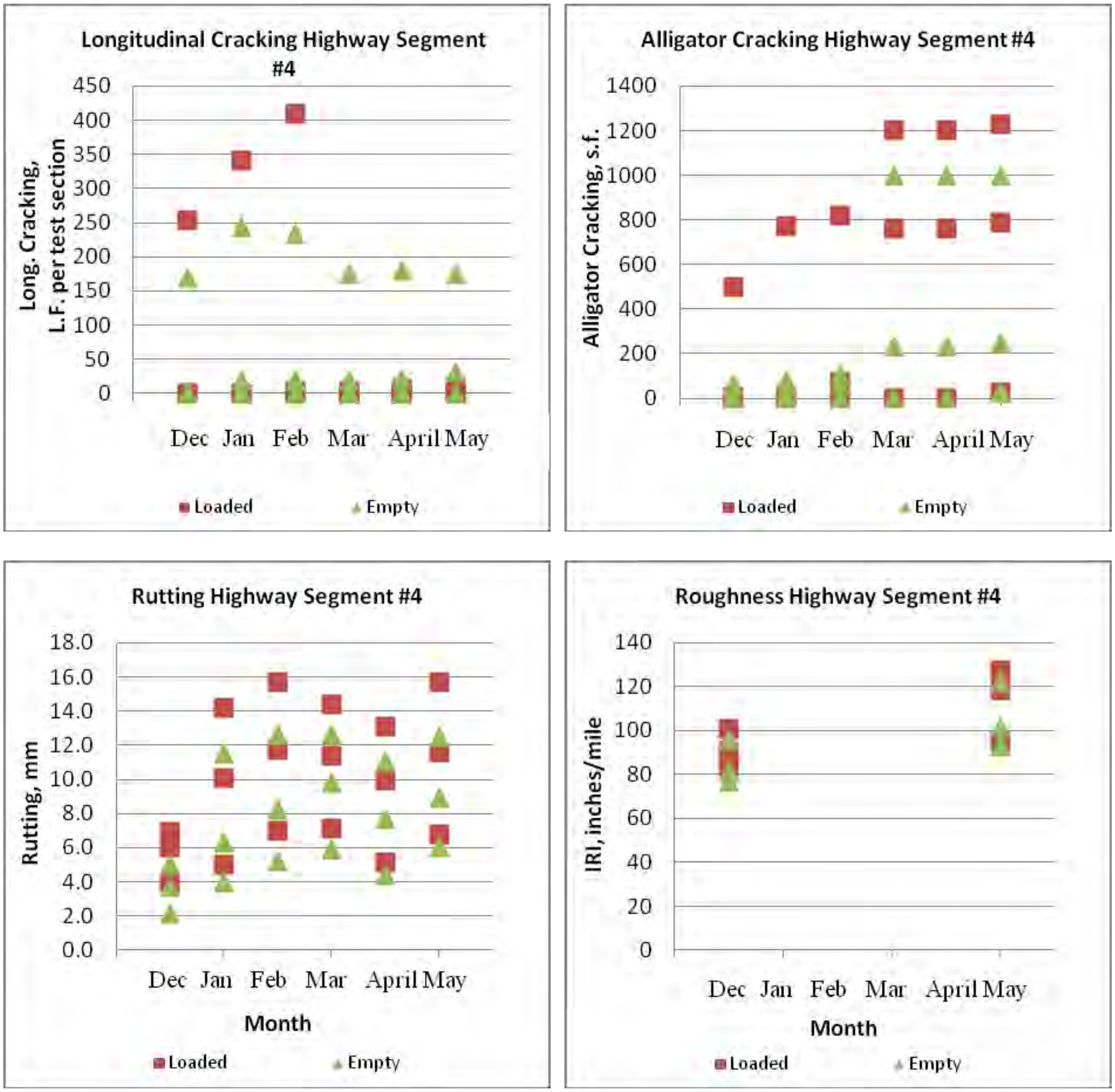


Figure 7.4 Highway Segment #4 Performance, STH 77 Washburn County, Age 12 years, Marshall MV-2

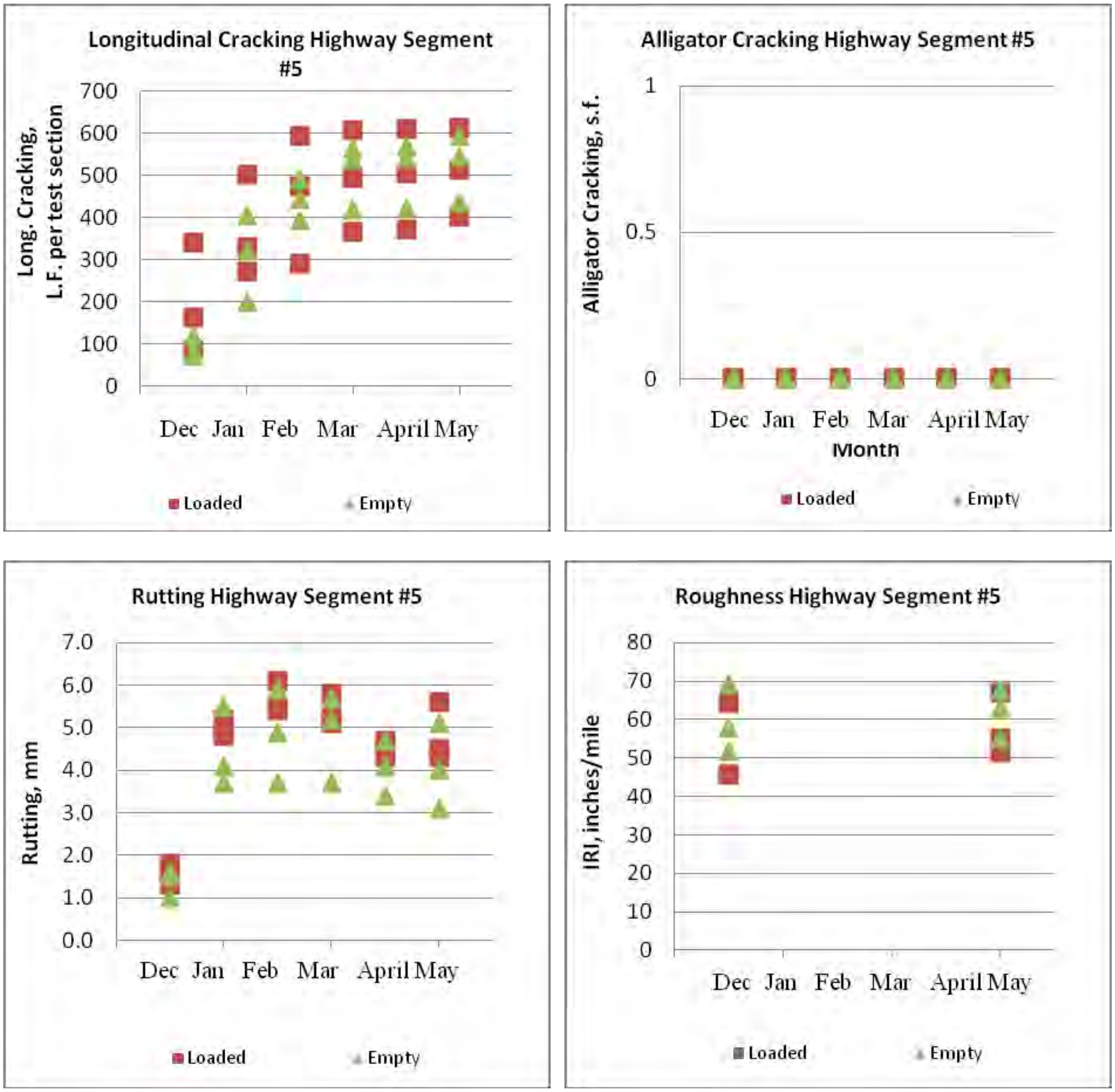


Figure 7.5 Highway Segment #5 Performance, STH 27 Sawyer County, Age 8 years, Superpave Warranty E-1

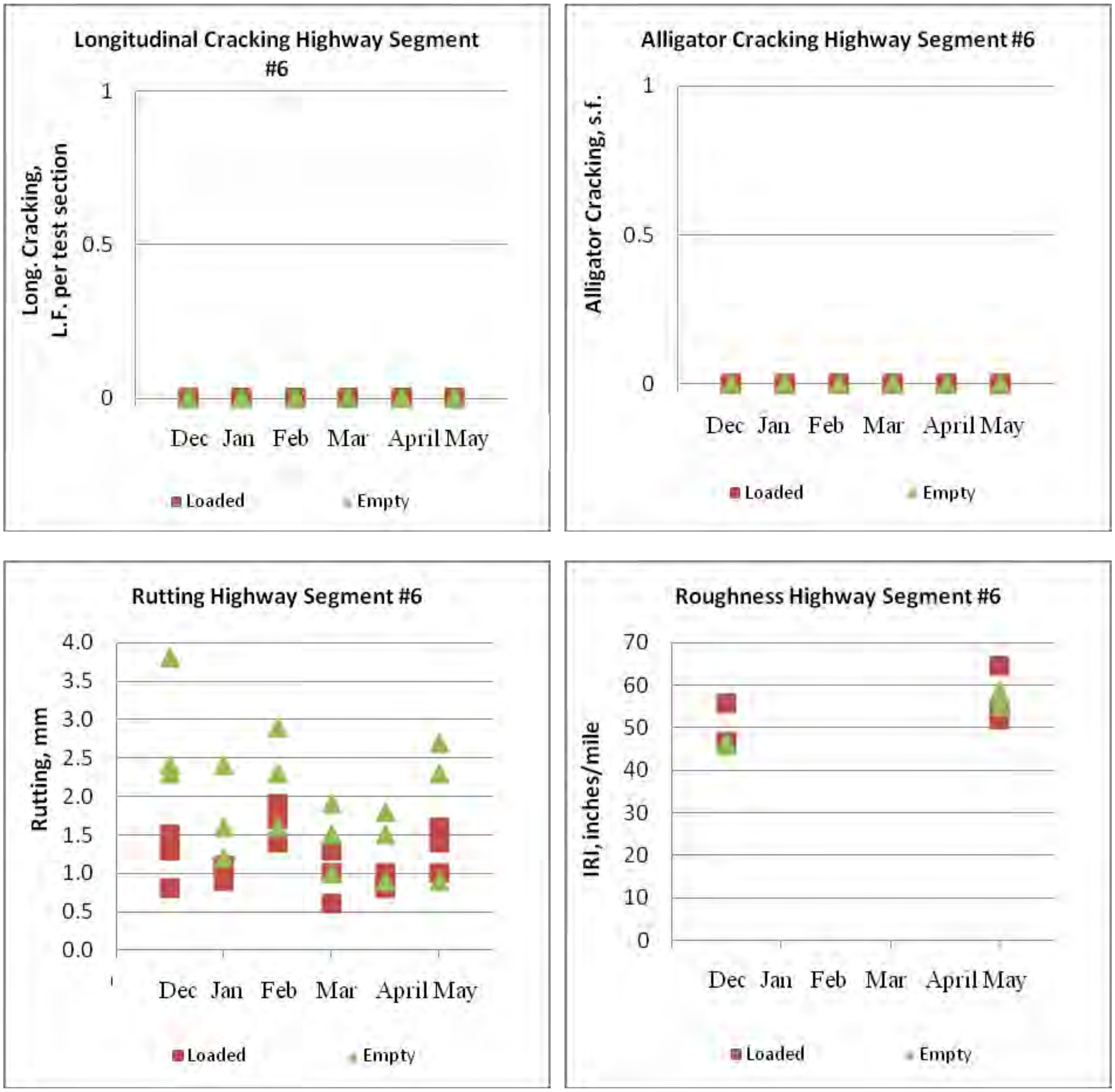


Figure 7.6 Highway Segment #6 Performance, STH 27/70 Sawyer County, Age 2 years, Superpave Warranty E-1

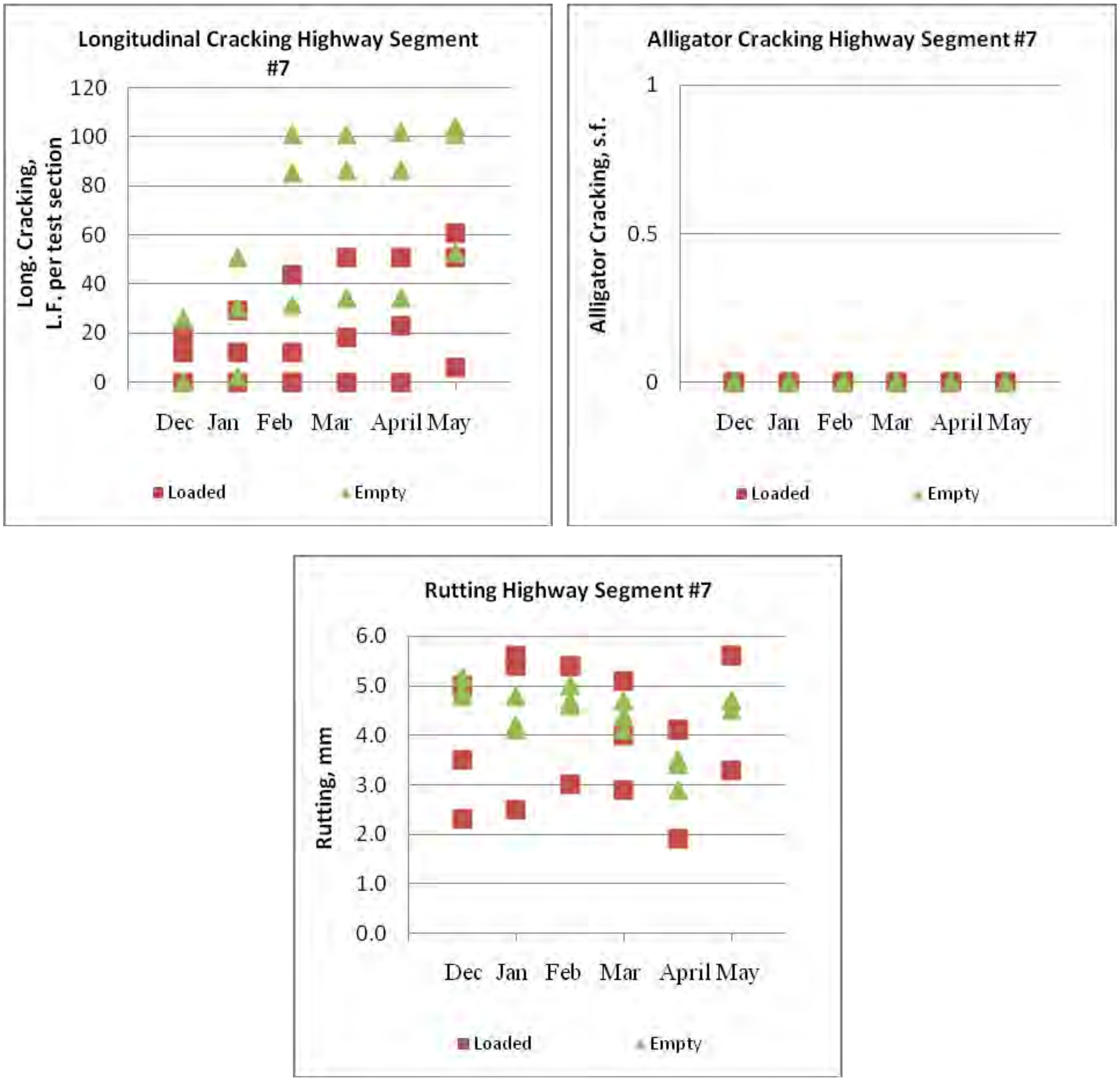


Figure 7.7 Highway Segment #7 Performance, STH 27/70 Sawyer County, Age 13 years, Marshall MV-2

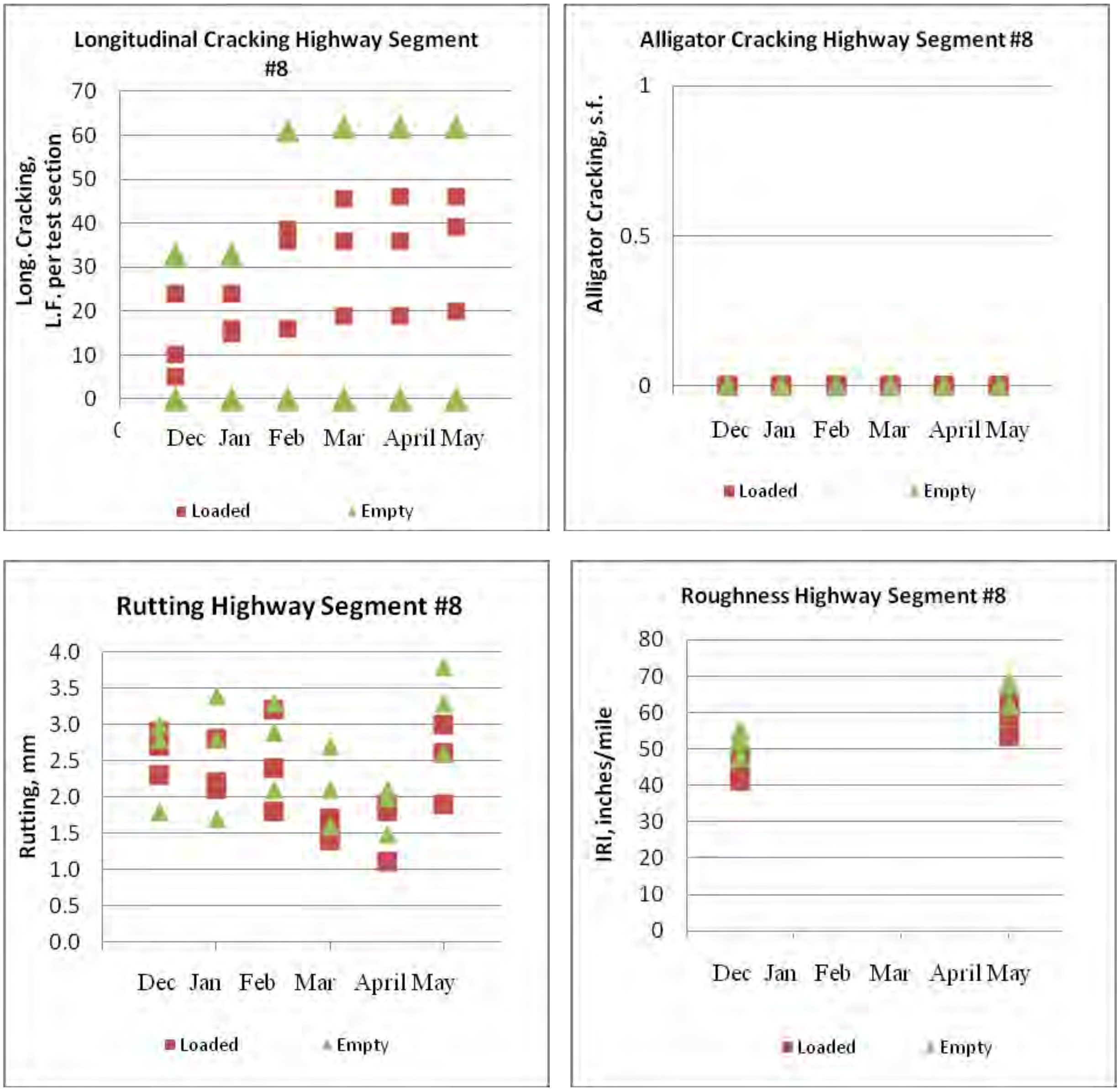


Figure 7.8 Highway Segment #8 Performance, STH 27 Rusk County, Age 7 years, Superpave E-1

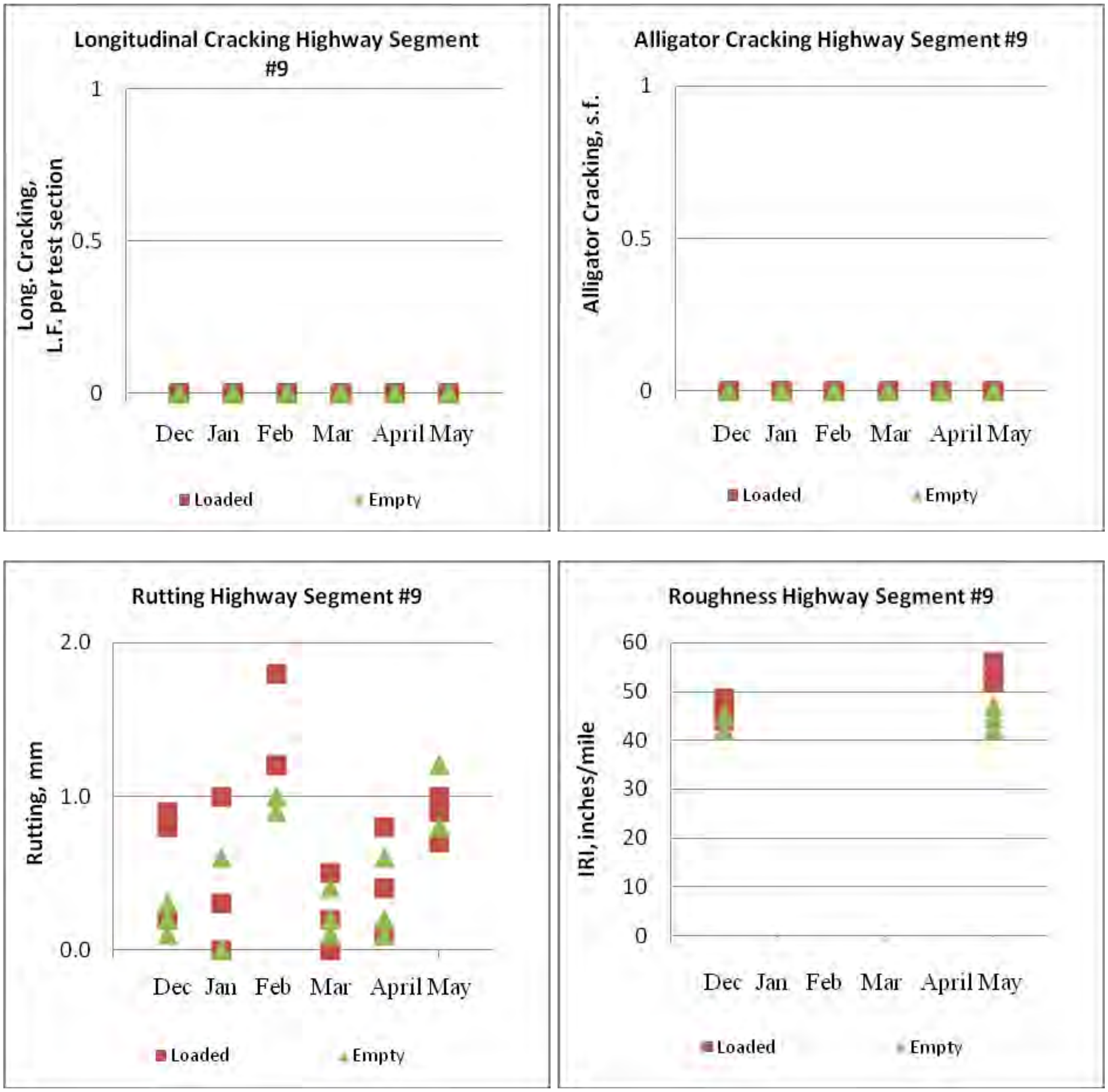


Figure 7.9 Highway Segment #9 Performance, STH 48 Sawyer County, Age 1 year, Superpave Warranty E-1

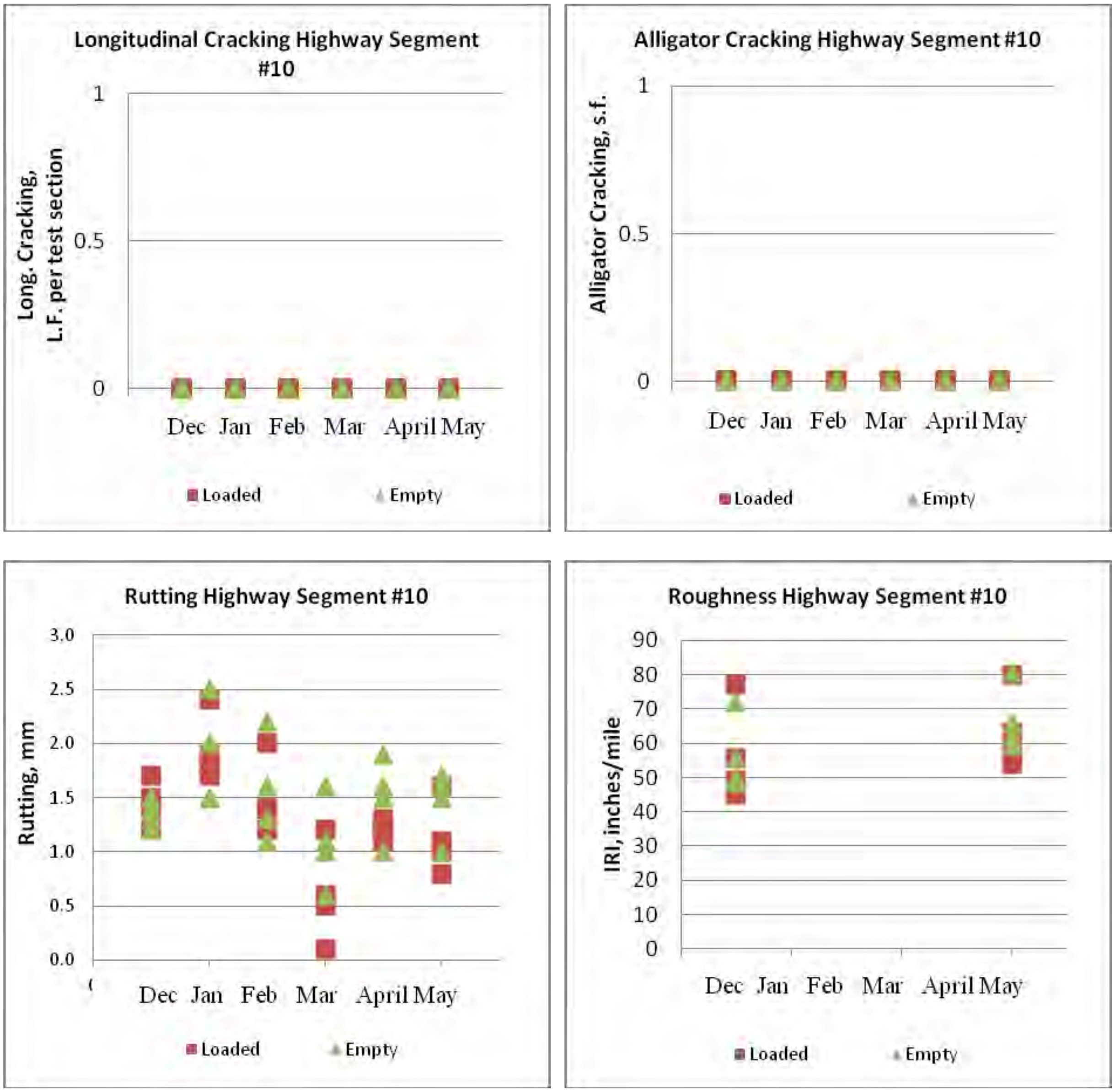
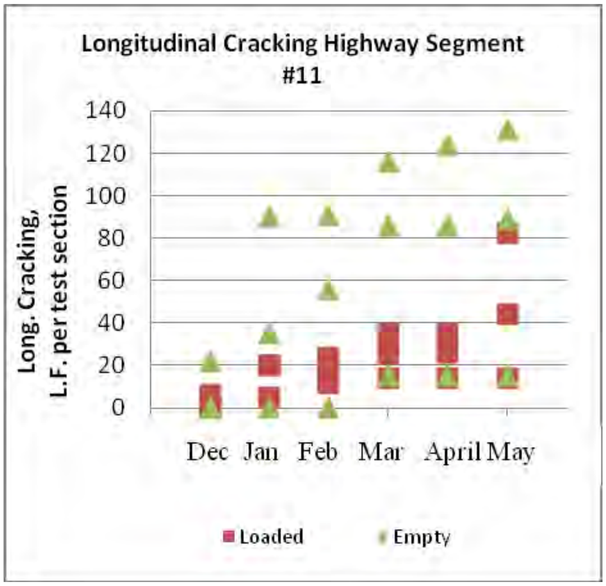
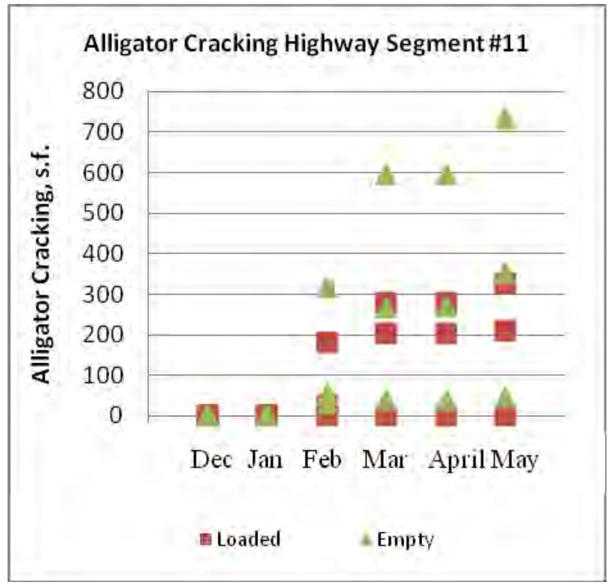


Figure 7.10 Highway Segment #10 Performance, STH 40 Rusk County, Age 1 year, Superpave Warranty E-1





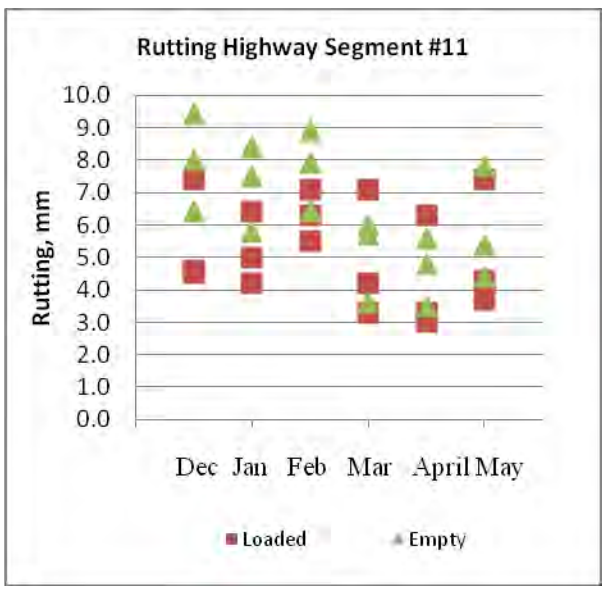


Figure 7.11 Highway Segment #11 Performance, STH 40 Sawyer County, Age 19 years, Marshall LV-1

7.4 Simple Linear Regression Models

Simple linear regression models were created to formally quantify changes in pavement performance over the evaluation period. All six months were used to develop statistical linear regression lines including the three months during Frozen Road Declaration (December, January, and February) and three months after the Spring Thaw Declaration in Zone 1 on March 9, 2012 (March, April, and May). This approach permitted a balanced sample of both frozen and spring thaw data points to create the line. Data from individual test sections were used to create the lines, as opposed to averaging the test section data for a highway segment. This approach incorporated natural field variability into the models. Although pavement performance changes may not be linear in nature, this method was chosen for simplicity, and to provide a comparative analysis detailed in the next section.

Statistical regression analysis is the relationship between a response or dependent variable and one or more independent variables. In this study, the dependent variable is pavement performance as measured by longitudinal cracking, alligator cracking, rutting, and ride (roughness). The independent variable is time as measured by monthly measurements of pavement condition. Equation 7.1 expresses the change in pavement performance over time using statistical parameter estimation.

$$Y_i = \beta_o + \beta_1 X_1 + \varepsilon_I \qquad (7.1)$$

Where,

Y_i = Dependent variable measured by monthly pavement condition;
X_i = Independent variable, month;
β_o = Intercept term;
β_1 = Slope term;
ε_I = Error or unexplained error term.

A statistical test determines if significant intercepts and slopes are found among monthly pavement condition measures. The coefficient of determination, R-squared value, is calculated to report the ability of month (independent variable) to explain changes in pavement condition (dependent variable), as shown by Equation 7.2. Higher R-squared values indicate greater model accuracy, with the maximum of 100 %.

$$R^2 = SSR/SST \qquad (7.2)$$

Where,

SSR = Regression sum of squares = $\sum(\hat{Y}_i - \bar{Y})^2$
SST = Total sum of squares: = $\sum(Y_i - \bar{Y})^2$

Table 7.1 summarizes the linear regression models by lane, performance measure, and highway segment.

Table 7.1 Simple Linear Regression Models

Age	Loaded Lane						Empty Lane					
	Highway Segment	Intercept	Significant	Slope	Significant	R-Square, %	Highway Segment	Intercept	Significant	Slope	Significant	R-Square, %
	(a) Alligator Cracking, s.f.						(a) Alligator Cracking, s.f.					
1	1	0	.	0	.		1	0	.	0	.	
7	2	0	.	0	.		2	0	.	0	.	
13	3	402.7	Yes	129.93	Yes	84.4	3	245.3	Yes	62.14	Yes	95.4
12	4	42.4	No	117.28	Marginal	18.0	4	-108.4	No	96.84	Yes	22.0
8	5	0	.	0	.		5	0	.	0	.	
2	6	0	.	0	.		6	0	.	0	.	
13	7	0	.	0	.		7	0	.	0	.	
7	8	0	.	0	.		8	0	.	0	.	
1	9	0	.	0	.		9	0	.	0	.	
1	10	0	.	0	.		10	0	.	0	.	
19	11	-110.5	No	84.41	Yes	37.2	11	-52.0	No	41.92	Yes	35.4
	(b) Longitudinal Cracking, l.f.						(b) Longitudinal Cracking, l.f.					
1	1	-1.4	No	0.62	No	12.6	1	0	.	0	.	
7	2	48.7	No	1.51	No	0.1	2	1.4	No	1.14	No	5.1
13	3	6.7	No	2.99	Marginal	54.9	3	117.1	Yes	7.48	No	23.9
12	4	144.9	Yes	-25.08	No	11.4	4	73.3	No	-0.59	No	0.0
8	5	220.3	Yes	56.52	Yes	41.5	5	114.0	Yes	80.83	Yes	69.2
2	6	0.0	.	0	.		6	0	.	0	.	
13	7	3.5	No	5.16	Marginal	18.6	7	4.5	No	15.05	Yes	46.7
7	8	9.6	No	2.22	No	2.2	8	11.4	Marginal	4.55	Yes	37.0
1	9	0.0	.	0	.		9	0	.	0	.	
1	10	0.0	.	0	.		10	0	.	0	.	
19	11	6.1	No	13.67	Yes	25.7	11	-4.1	No	7.44	Yes	46.2
	(c) Rutting, mm						(c) Rutting, mm					
1	1	-0.3	Yes	0.17	Yes	70.5	1	-0.4	Yes	0.17	Yes	59.1
7	2	1.1	Yes	0.30	Yes	43.3	2	1.6	Yes	0.39	Yes	36.1
13	3	4.1	Yes	0.56	No	41.1	3	3.3	Marginal	0.91	Marginal	62.3
12	4	7.1	Yes	0.76	No	11.8	4	4.5	Yes	0.87	Marginal	20.2
8	5	2.9	Yes	0.43	Yes	25.1	5	2.7	Yes	0.34	Marginal	16.3
2	6	1.1	Yes	0.02	No	1.0	6	2.7	Yes	-0.19	Marginal	16.1
13	7	3.9	Yes	0.05	No	0.5	7	5.0	Yes	-0.17	Marginal	21.2
7	8	2.5	Yes	-0.01	No	0.5	8	2.6	Yes	-0.11	No	12.3
1	9	0.8	Yes	-0.02	No	0.3	9	0.0	No	0.12	Marginal	20.5
1	10	1.6	Yes	0.01	No	0.2	10	1.7	Yes	-0.11	Marginal	17.1
19	11	8.6	Yes	-0.61	Yes	37.6	11	5.9	Yes	-0.18	No	4.0
	(d) Ride, in/mi						(d) Ride, in/mi					
1	1	46.7	Yes	1.05	No	7.9	1	40.6	Yes	1.65	No	48.9
7	2	52.1	Yes	6.12	Marginal	58.3	2	52.1	Yes	5.20	Marginal	56.3
13	3	111.6	.	1.81	.	100.0	3	109.9	.	1.60	.	100.0
12	4	87.1	Yes	4.46	No	52.0	4	80.6	Yes	4.10	No	49.0
8	5	50.8	Yes	1.18	No	12.6	5	59.0	Yes	0.47	No	3.4
2	6	48.1	Yes	1.46	No	34.7	6	44.1	Yes	2.15	Yes	96.2
13	7	N/A					7	N/A				0.0
7	8	48.9	Yes	2.85	Yes	84.9	8	41.4	Yes	2.82	Yes	82.0
1	9	44.2	Yes	1.60	Yes	83.4	9	43.9	Yes	0.09	No	1.8
1	10	55.8	Yes	1.84	No	18.0	10	53.8	Yes	1.69	No	14.6
19	11	N/A					11	N/A				

N/A, No data available; Yes, p-value < 0.05; Marginal, 0.05 < p-value < 0.10; No, p-value > 0.10

Sample size: n=18 for loaded and empty lane models, except n=6 on Segment #3 and n=24 on Segment #10.

The hypothesis test results from these linear regression models for the loaded lane and empty lane are summarized in Table 7.2.

Table 7.2 Statistically determined Pavement Performance Rate Changes for 11 Highway Segments

Performance Measure	Loaded Lane			Empty Lane		
	Increase	No Change[1]	Decrease	Increase	No Change[1]	Decrease
Alligator Cracking	3 Age 12-19	8 Age 1-13	0	3 Age 12-19	8 Age 1-13	0
Longitudinal Cracking	4 Age 8-19	7 Age 1-12	0	4 Age 7-19	7 Age 1-13	0
Rutting	3 Age 1-8	7 Age 1-13	1 Age 19	6 Age 1-13	2 Age 7-19	3 Age 1-13
Ride[2]	3 Age 1-7	6 Age 1-12	0	3 Age 2-7	6 Age 1-12	0

[1] Slope was either zero or not statistically significant.
[2] Ride was measured in 9 of the 11 highway segments.

Results are as follows for the loaded lane:

- Alligator cracking increased in 3 segments with age ranging from 12 to 19 years; 8 segments had zero or no statistically significant slope with age ranging from 1 to 13 years. The 3 segments that showed progression in alligator cracking were constructed of Marshall mix design, while 7 of the 8 segments that did not show any progression in alligator cracking were constructed of Superpave mix design.
- Longitudinal cracking increased in 4 segments with age ranging from 8 to 19 years; 7 segments had zero or no statistically significant slope with age ranging from 1 to 12 years. Of the 4 segments that showed progression in longitudinal cracking, 3 were constructed of Marshall mix design. Of the 7 segments that did not show any progression in longitudinal cracking, 6 were constructed of Superpave mix design.
- Rutting increased in 3 segments with age ranging from 1 to 8 years; 1 segment had a decrease at age 19 years; 7 segments had zero or no statistically significant slope with age ranging from 1 to 13 years.
- Roughness increased in 3 of 9 segments with age ranging from 1 to 7 years; 6 of 9 segments had zero or no statistically significant slope with age ranging from 1 to 12 years.

The following results can be concluded for the empty lane:

- Alligator cracking increased in the same 3 Marshall mix design segments as the loaded lane with age ranging from 12 to 19 years. The same 8 segments ranging in age from 1 to 13 years as the loaded lane had zero or no statistically significant slope. Of the 8 segments, 7 were constructed of Superpave mix design.

- Longitudinal cracking increased in 4 segments of which 3 were the same as the loaded lane with age ranging from 7 to 19 years; 2 of the 4 segments that showed progression in longitudinal were constructed of Marshall mix design, while the remainder were constructed of Superpave design. Seven segments had zero or no statistically significant slope with age ranging from 1 to 13 years; 5 of the 7 segments were constructed of Superpave mix design.
- Rutting increased in 6 segments with age ranging from 1 to 13 years; decreased in 3 segments with age ranging from 1 to 13 years; 2 segments had zero or no statistically significant slope with age ranging from 7 to 19 years.
- Roughness increased in 3 of 9 segments with age ranging from 2 to 7 years, with the IRI increasing at a monthly rate from 2 to 6 in/mile in the loaded lane and 2 to 5 in/mile in the empty lane; 6 of 9 segments had zero or no statistically significant slope with age ranging from 1 to 12 years.

7.5 Impact of Mix Design Type on Performance

The monthly data plots and results from the regression models for the individual segments revealed that segments constructed of Superpave mix design exhibited better performance than those constructed of Marshall mix design. A one-way analysis of variance (ANOVA) was performed to check the validity of this observation. The ANOVA was used to test the hypothesis of equal population means by choosing between the following two hypotheses:

$$H_0: \mu_{Superpave} = \mu_{Marshall}$$
$$H_A: \mu_{Superpave} \neq \mu_{Marshall}$$

$\mu_{Superpave}$ = Mean value of the performance measure for segments constructed of Superpave mix design.
$\mu_{Marshall}$ = Mean value of the performance measure for segments constructed of Marshall mix design.

The results of the ANOVA tests are plotted in Figures 7.12 and 7.13 and summarized in Table 7.3 for both winter (Dec-Feb) and spring (Mar-May). In Figures 7.12 and 7.13, means are significantly different where the Least Significant Difference (LSD) intervals do not overlap. In LSD, the intervals are scaled to control the error rate at 5%. Figures 7.12 and 7.13 show statistically significant differences between Superpave and Marshall mix segments with respect to alligator cracking and rut depth. Marshall segments exhibited higher mean values in these two performance measures compared to Superpave segments. There is however, no significant difference between the two mix design types when longitudinal cracking is the performance measure.

Table 7.3 ANOVA Results for Impact of Mix Type on Performance Measures

Performance Indicator	Significance of Mix Type	
	Winter (Dec-Feb)	Spring (Mar-May)
Alligator Cracking	XXX	XXX
Longitudinal Cracking	n/s	n/s
Rut Depth	XXX	XXX
XXX=Highly significant, p-value ≤0.05 n/s= Not significant, p-value >0.05		

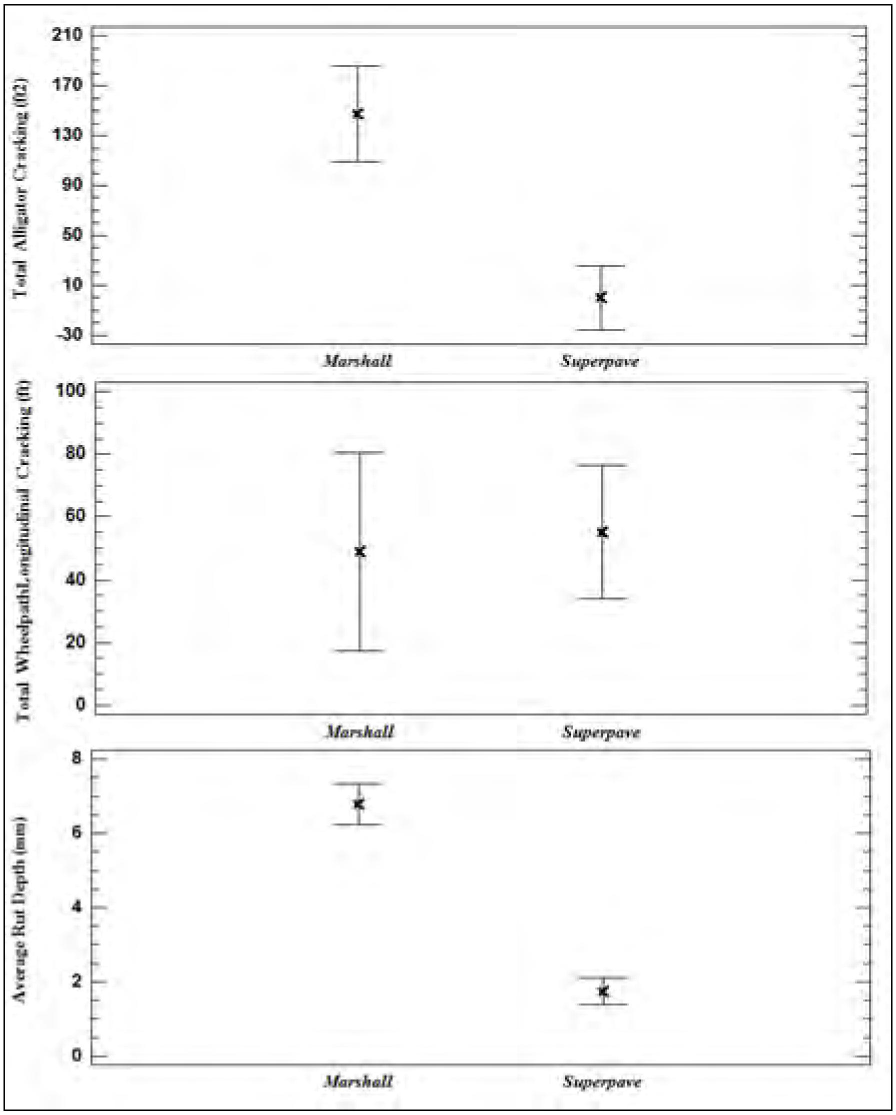


Figure 7.12 Means and 95% LSD Interval Plots for Mix Design Type on Performance (*Dec-Feb*)

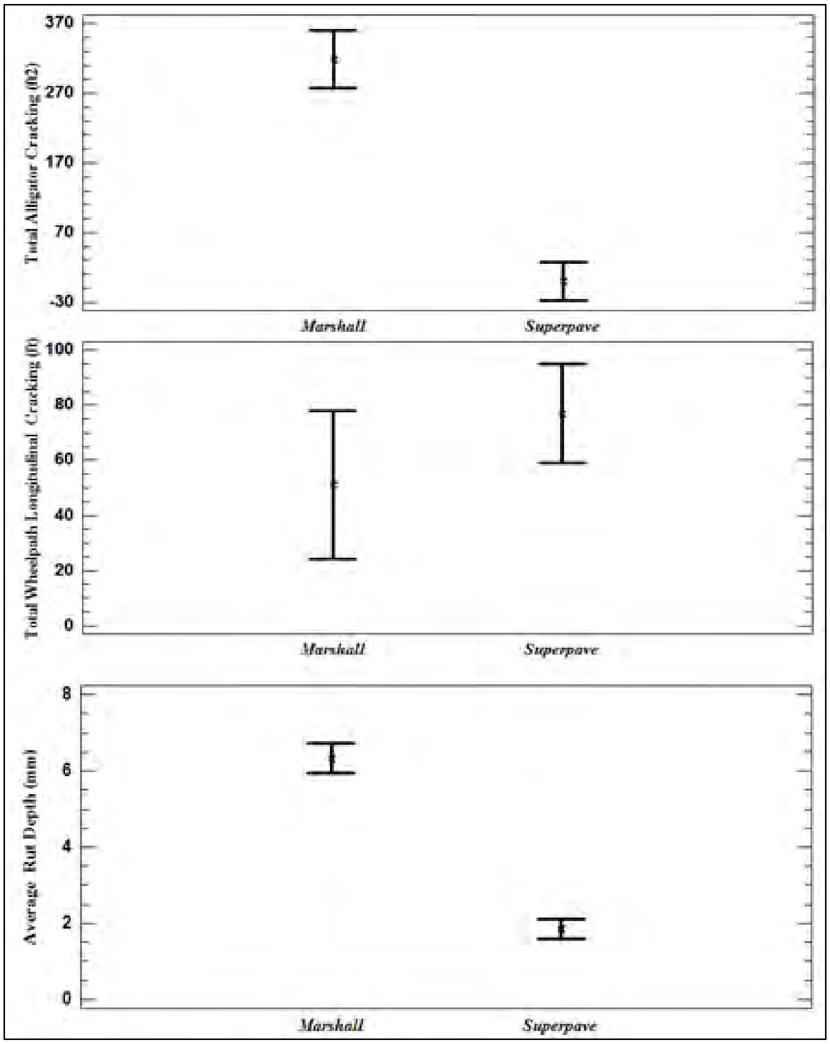


Figure 7.13 Means and 95% LSD Interval Plots for Mix Design Type on Performance (*Mar-May*)

7.6 Statistical Comparison of Regression Parameters for Loaded and Empty Lanes

A statistical comparison was made between changes in pavement condition between highway lanes having either predominantly loaded 6-axle logging trucks or empty 6-axle logging trucks. The comparison was made individually for each of the 11 highway segments. This approach allowed the analysis to block out the effects of different pavement bases, asphalt layer thicknesses, asphalt materials, age, and all other factors that may have an effect on the direct comparison. Furthermore, this approach allowed a split sample comparison where the only variable changed in the comparison was the measured vehicle traffic on each opposing lane.

Of primary interest in this study is whether the slope and intercept values between loaded and empty lanes are different or not. A statistical difference would suggest pavement condition changes between 6-axle loaded and empty lanes. The following hypothesis statements were prepared:

Hypothesis #1

H_O: Intercept in pavement condition in loaded and empty lanes are equal ($\beta_{o,Loaded} = \beta_{o,Empty}$).

H_A: Intercept in pavement condition in loaded and empty lanes are not equal ($\beta_{o,Loaded} \neq \beta_{o,Empty}$).

Hypothesis #2

H_O: Slope of pavement condition in loaded and empty lanes are equal ($\beta_{1,Loaded} = \beta_{1,Empty}$).

H_A: Slope of pavement condition in loaded and empty lanes are not equal ($\beta_{1,Loaded} \neq \beta_{1,Empty}$).

The analysis of covariance (ANCOVA) was used to compare the two regression lines (loaded and empty lanes) by testing the effect of the categorical/independent variable (loaded or empty lane) on the dependent variable (pavement condition) while controlling the effect of the continuous co-variable (monthly intercept and slope). The regression lines are compared by studying the interaction of the categorical variable (i.e., loaded or empty lane) with the continuous independent variable (month). If the interaction is significantly different from zero it means that the effect of the continuous covariate on the response depends on the level of the categorical factor. In other words, the regression lines have different slopes. This would indicate that the rate (slope parameter) of pavement condition deterioration is different among the loaded and empty lanes. All six months (three before spring thaw and three after spring thaw declaration) were included in the models to determine whether a statistically significant slope exists across the study period. A significant treatment effect with no significant interaction shows that the covariate has the same effect for all levels of the categorical factor. In other words, the rate of pavement condition deterioration is the same between variables. However, since the treatment effect is important, the regression lines although parallel have different intercepts. Finally, if the treatment effect is not significant nor its interaction with the covariate (but the covariate is significant), this means there is a single regression line.

Multiple regression models using ANCOVA methods were then developed to statistically compare if the intercepts and slopes were different between loaded and empty lanes, as shown by Equation 7.3.

$$Y_i = \beta_o + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_k X_{ki} + \varepsilon_I \qquad (7.3)$$

Where,

Y_i = Dependent variable measured by pavement condition;
X_{ni} = Independent variable measured by month;
β_o = Intercept term;
β_n = Slope term ($n \geq 1$); and
ε_I = Error or unexplained error term.

Table 7.4 provides results of the statistical hypothesis tests for difference on intercepts and slopes for loaded and empty log truck lanes.

Table 7.4 Comparison of Linear Relationships of Loaded and Empty Lanes

Highway Segment	Age	Intercept Loaded Lane	Intercept Significant	Intercept Loaded - Empty Lane	Intercept Difference Significant	Slope Loaded Lane	Slope Significant	Slope Loaded - Empty Lane	Slope Difference Significant	R-Square, %	Adjusted R-Square, %
(a) Alligator Cracking, s.f.											
1	1	N/T	.	.	.	.	.	.	.	.	.
2	7	N/T	.	.	.	.	.	.	.	.	.
3	13	402.7	Yes	-157.4	No	129.9	Yes	-67.8	Yes	93.5	91.0
4	12	42.4	No	-150.8	No	117.3	Yes	-20.4	No	24.8	17.7
5	8	N/T	.	.	.	.	.	.	.	.	.
6	2	N/T	.	.	.	.	.	.	.	.	.
7	13	N/T	.	.	.	.	.	.	.	.	.
8	7	N/T	.	.	.	.	.	.	.	.	.
9	1	N/T	.	.	.	.	.	.	.	.	.
10	1	N/T	.	.	.	.	.	.	.	.	.
11	19	-110.5	No	58.5	No	84.4	Yes	-42.5	No	40.3	34.7
(b) Longitudinal Cracking, l.f.											
1	1	-1.4	No	1.4	No	0.6	Yes	-0.6	No	15.1	7.1
2	7	48.7	No	-47.3	No	1.5	No	-0.4	No	17.2	9.5
3	13	6.7	No	110.4	Yes	3.0	No	4.5	No	93.8	91.5
4	12	144.9	Yes	-71.6	No	-25.1	No	24.5	No	8.0	-0.7
5	8	220.3	Yes	-106.4	No	56.5	Yes	24.3	No	56.9	52.9
6	2	.	.	.	.	.	.	.	.	.	.
7	13	3.5	No	0.9	No	5.2	No	9.9	Yes	55.6	51.4
8	7	9.6	No	1.7	No	2.2	No	2.3	No	14.1	6.0
9	1	.	.	.	.	.	.	.	.	.	.
10	1	.	.	.	.	.	.	.	.	.	.
11	19	6.1	No	-10.1	No	13.7	Yes	-6.2	No	40.3	35.3
(c) Rutting, mm											
1	1	-0.3	Yes	-0.1	No	0.17	Yes	0.00	No	64.6	61.3
2	7	1.1	Yes	0.5	No	0.30	Yes	0.09	No	47.4	42.4
3	13	4.1	Yes	-0.8	No	0.56	No	0.36	No	55.3	38.5
4	12	7.1	Yes	-2.6	No	0.76	No	0.11	No	22.7	15.4
5	8	2.9	Yes	-0.2	No	0.43	Yes	-0.09	No	23.0	15.8
6	2	1.1	Yes	1.6	Yes	0.02	No	-0.21	Marginal	42.1	36.7
7	13	3.9	Yes	1.0	No	0.05	No	-0.22	No	6.9	-1.9
8	7	2.5	Yes	0.1	No	-0.01	No	-0.10	No	8.2	-0.5
9	1	0.8	Yes	-0.8	Marginal	-0.02	No	0.14	No	15.2	7.2
10	1	1.6	Yes	-0.1	No	0.00	No	-0.10	No	24.7	19.6
11	19	8.6	Yes	-2.8	Yes	-0.61	Yes	0.44	No	32.5	26.2
(d) Ride, in/mi											
1		46.7	Yes	-6.1	No	1.05	No	0.60	No	24.5	-3.8
2		52.1	Yes	0.1	No	6.12	Yes	-0.93	No	57.7	41.9
3		N/T	.	.	.	.	.	.	.	.	.
4		87.1	Yes	-6.5	No	4.46	Marginal	-0.36	No	53.6	36.2
5		50.8	Yes	8.3	No	1.18	No	-0.71	No	21.2	-8.4
6		48.1	Yes	-3.9	No	1.46	Marginal	0.69	No	62.3	48.2
7		N/T	.	.	.	.	.	.	.	.	.
8		48.9	Yes	-7.5	Marginal	2.85	Yes	-0.03	No	86.7	81.7
9		44.2	Yes	-0.3	No	1.60	Yes	-1.51	Yes	83.7	77.5
10		55.8	Yes	-2.1	No	1.84	No	-0.16	No	17.1	-3.6
11		N/T	.	.	.	.	.	.	.	.	.

N/T, No statistical test; Yes, p-value < 0.05; Marginal, 0.05 < p-value < 0.10; No, p-value > 0.10

Table 7.5 summarizes the results of the comparison between loaded and empty linear slopes. The following can be concluded for the comparison of linear slopes representing the rate of pavement condition change across the evaluation period.

- Alligator cracking and longitudinal cracking slopes were only significantly different on 1 of 11 segments at age 13 years (Marshall-design pavement mixtures have been replaced with Superpave mixture designs); no statistical slope difference on 10 of 11 segments with age ranging from 1 to 19 years.
- Rutting slopes were only significantly different on 1 of 11 segments at age 2 years; no statistical slope difference on 10 of 11 segments with age ranging from 1 to 19 years.
- Ride (roughness) was only significantly different on 1 of 8 segments at age 1 year; no statistical slope difference on 7 of 8 segments with age ranging from 1 to 12 years.

Table 7.5 Statistical Difference of Pavement Performance Rate Changes between Loaded and Empty Logging Truck Lanes

Performance Measure	Difference between Slope of Loaded and Empty Lanes		
	Increase	No Change[1]	Decrease
Alligator Cracking	1 Age 13	10 Age 1-19	0
Longitudinal Cracking	1 Age 13	10 Age 1-19	0
Rutting	1 Age 2	10 Age 1-19	0
Ride[1]	1 Age 1	7 Age 1-12	0
[1]Ride was measured in 9 of the 11 highway segments, and statistically tested in 8 of 11 segments.			

7.7 Changes in Pavement Condition during Spring Thaw Months

An analytical approach tested changes in pavement condition differences between adjoining lanes immediately after spring thaw. As discussed in the previous chapter, a paired comparison was designed in this study using adjoining lanes where the only random variable was the level of loaded and empty trucks.

On March 9th, 2012, the Spring Thaw Declaration was issued for Zone 1 that included all pavement segments in this study. During the week of March 19-23 the research team collected traffic and pavement distress data on all highway segments. Data collection also occurred in April and May. A statistical test determined if there was a difference in pavement condition between loaded and empty lanes of logging truck traffic immediately after Spring Thaw declaration. The dependent variable was defined as the change or delta in pavement condition as shown by Equation 7.4.

$$\text{Pavement Condition } \Delta = \text{Pavement Condition}_{\text{Month j}} - \text{Pavement Condition}_{\text{Month i}} \qquad (7.4)$$

Where,

Pavement Condition $_{\text{Month i}}$ = Cracking or Rutting in Month i;
Pavement Condition $_{\text{Month j}}$ = Cracking or Rutting in Month j;
$i < j$; and
i and j are integer values.

The pavement condition delta between the loaded and empty lanes was found using Equation 7.5. The split-sampling design allowed for a direct comparison of loaded and empty lanes without the effects of different pavement structures and location.

$$\text{Pavement Condition } \Delta \text{ Loaded minus Empty Lane} =$$
$$\text{Pavement Condition } \Delta \text{ Loaded}_{\text{Month j}} - \text{Pavement Condition } \Delta \text{ Empty}_{\text{Month i}} \qquad (7.5)$$

Where,

Pavement Condition Δ Loaded $_{\text{Month i}}$ = Cracking or Rutting change in loaded logging truck lane in Month j; and
Pavement Condition Δ Empty $_{\text{Month i}}$ = Cracking or Rutting change in empty logging truck lane in Month i.

A statistical hypothesis test was stated to determine whether the mean difference of loaded minus empty lanes were different from zero during spring thaw months as follows:

H_O: Pavement Condition Δ Loaded minus Empty equals zero (difference = 0).

H_A: Pavement Condition Δ Loaded minus Empty does not equal zero (difference ≠ 0).

Equation 7.6 provides the basic equation for the t test statistic based upon variability and sample size:

$$t = \frac{(\bar{X} - \mu)}{\left(\frac{s_X}{\sqrt{n}}\right)} \tag{7.6}$$

Where,

t = standardized t statistic;

$\bar{X}$ = average paired difference of pavement condition of loaded and empty lanes;

μ = population mean, set to zero as a control null value;

s_X = sample standard deviation; and

n = sample size.

Table 7.6 summarizes the results of the statistical t-tests for the 11 highway segments. Small sample sizes were used in the comparison for each segment (n=3 or n=4); it must be noted that the Students *t* distribution is designed for small sample sizes. The predominant conclusion was no difference in pavement condition between loaded and empty 6-axle logging truck lanes during the March 2012 Spring Thaw. The only significant difference for longitudinal cracking was the 19-year old Highway #11 segment where there was 17 l.f. of additional cracking. From a practical viewpoint, this increase may or may not be considered negligible, however, from a formal hypothesis test the mean change in cracking length is of significant magnitude when measured against the underlying variability and sample size. There were three highway segments having a significant difference in rutting; in one segment the empty lane had greater rutting (2.5 mm) while the 7-year old Highway Segments #2 and #8 each had greater rutting (0.6 mm) in the loaded truck travel lane.

Table 7.6 Statistical One-Sample t-test Results for March 2012 Pavement Performance Difference between Loaded and Empty Logging Truck Lanes

			Alligator Cracking, s.f.			Longitudinal Cracking, l.f.			Rutting, mm		
Highway Segment	Age	N	Mean	Std. Dev.	Significant Difference	Mean	Std. Dev.	Significant Difference	Mean	Std. Dev.	Significant Difference
1	1	3	0	0	No	0	0	No	0.2	0.2	No
2	7	3	0	0	No	0.1	1.4	No	0.6	0.0	Yes
3	13	1	307.7	.	N/T	-20.5	.	N/T	-0.4	.	N/T
4	12	3	2.1	520	No	-116.6	202.9	No	-2.5	1.3	Marginal
5	8	3	0	0	No	-27.0	46.6	No	-0.6	0.7	No
6	2	3	0	0	No	0	0	No	0.2	0.7	No
7	13	3	0	0	No	3.2	2.9	No	-0.5	1.5	No
8	7	3	0	0	No	-3.0	3.0	No	0.6	0.2	Yes
9	1	3	0	0	No	0	0	No	-0.9	1.4	No
10	1	4	0	0	No	0	0	No	0.2	1.8	No
11	19	3	74.7	91.3	No	16.7	9.3	Marginal	-2.3	3.3	No
All	---	32	16.8	145.9	No	-12.5	63.8	No	-0.5	1.6	No

N/T, No statistical test; Yes, p-value < 0.05; Marginal, 0.05 < p-value < 0.10; No, p-value > 0.10

7.8 Changes in Pavement Condition by Vehicle Class

A primary objective in this study is to identify whether certain vehicle classes are more damaging than others during Spring Thaw, and the possibility of lessening the impact of these heavy loads. This objective was investigated by determining if there is a relationship between monthly changes in pavement condition during Spring Thaw with repeated loading by certain truck classes, as well as other traffic measures such as AADTT and total number of all vehicles per day. The dependent variable was defined as the change or delta in pavement condition as trucks are applied to the pavement, as described earlier by Equation 7.4. Pavement Condition Δ is a random dependent variable that responds to independent vehicle loading. Traffic measures were treated as independent variables.

A hypothesis test was stated to determine if the mean level among monthly changes in load-related cracking and rutting were significantly different or not from traffic measures. The null hypothesis, H_O, hypothesized they were not different, while the alternative hypothesis, H_A, hypothesized they were different:

H_O: Pavement Condition Δ average is not different (mean difference = 0).

H_A: Pavement Condition Δ average is different (mean difference ≠ 0).

A formal statistical technique determined if certain traffic measures and FHWA truck classes caused changes in monthly pavement condition delta, as measured by alligator cracking, longitudinal cracking and rutting. Analysis of variance (ANOVA) methods were selected as the statistical technique, where a comparison was made among the means of multiple observations or treatments (i.e., traffic measures). General Linear Models (GLM) specific to ANOVA methods were selected, where the mean of the data is first computed, then the variation of each independent variable in explaining deviations of the mean is computed. Regression modeling was considered, but ANOVA was chosen due to statistical efficiency. The key distinction between ANOVA and regression is that the ANOVA procedure first finds the mean of the data, then the function, while the regression procedure first finds the function, then the mean.

Two standard statistics were calculated and used to determine significance: (1) the F-ratio and (2) the p-value. The F-ratio calculated the ratio of mean variances in factors with error, and was then plotted on the F-distribution to determine a probability level of significance, or p-value. High F-ratios yielding p-values equal to or less than 5 % would indicate the null hypothesis should be rejected (i.e., 95 % probability level). Marginal significance with p-values between 0.05 and 0.10 are reported. Equation 7.7 shows how the F-value is calculated using the mean squares (MS) of the factor divided by the MS of the unexplained error:

$$F_{Factor} = \frac{MS(\text{Traffic Measure})}{MS(\text{Error})} \tag{7.7}$$

The output provided two estimates for the mean square: (1) Type I when the variable is entered first in the model, and (2) Type III when it is entered last. Type III Sum of Squares provides the most rigorous hypothesis test since it accounts for remaining unexplained variation when entered last in the model. This measurement technique provides a measure of variable robustness by the relative ability to accumulate sum of squares against the other previously-entered competing variables.

Table 7.7 provides the results of the statistical analysis for pavement condition delta for March, April, and May. Including these three months from the beginning of Spring Thaw on March 9, 2012 in Zone 1 allowed a time-lapse understanding of the relationship between vehicle loading and distresses.

Table 7.7 Monthly Pavement Condition Changes by Traffic Measures after Spring Thaw Declaration

Traffic Measure	Alligator Cracking			Longitudinal Cracking			Rutting		
	March	Apri	May	March	April	May	March	Apri	May
Sample size, n	56	64	64	56	64	64	56	64	64
Total all Vehicles per day	No	No	No	Marginal	Yes	No	No	No	Yes
Total all Trucks	No	No	No	No	No	No	Yes	No	No
Total Trucks Loaded	No	No	Marginal	No	No	No	Yes	No	No
Total Trucks Empty	No	No	No	No	No	Yes	Yes	No	No
AADTT All Loaded Trucks	No	No	Marginal	No	No	No	Yes	No	No
AADTT All Empty Trucks	No	No	No	No	No	Yes	Yes	No	No
FHWA Class 6 Loaded Trucks	No	n/t	No	No	n/t	Yes	No	n/t	Yes
FHWA Class 6 Empty Trucks	No	No	No	Marginal	No	No	No	Yes	No
FHWA Class 8 Loaded Trucks	n/t	nt	n/t	n/t	n/t	n/t	n/t	n/t	n/t
FHWA Class 8 Empty Trucks	n/t	No	No	n/t	No	Yes	n/t	No	Marginal
FHWA Class 9 Loaded Trucks	n/t	No	No	n/t	No	No	n/t	No	No
FHWA Class 9 Empty Trucks	No	No	No	No	No	No	No	No	No
FHWA Class 9 ESAL	No	No	No	No	No	No	No	Yes	Yes
FHWA Class 10 Loaded Trucks	No	No	No	No	No	No	Yes	No	Yes
FHWA Class 10 Empty Trucks	No	No	No	No	No	No	Yes	Yes	Yes
FHWA Class 10 ESAL	No	No	Marginal	Yes	Yes	No	Yes	Yes	Yes
FHWA Class 11 Loaded Trucks	n/t	n/t	n/t	n/t	n/t	n/t	n/t	n/t	n/t
FHWA Class 11 Empty Trucks	n/t	n/t	n/t	n/t	n/t	n/t	n/t	n/t	n/t
FHWA Class 12 Loaded Trucks	No	No	n/t	No	No	n/t	No	No	n/t
FHWA Class 12 Empty Trucks	No	No	No	No	No	No	No	Yes	Marginal

n/t = No truck classes observed; No = not significant; Yes = Highly Significant, p-value < 0.05; Marginal, 0.05<p-value<0.10

The hypothesis test results conclude the following by distress type and month:

- Alligator cracking changes were only related to total loaded trucks, AADTT of all loaded trucks, and ESALs per day for FHWA class 10 only in the month of May. There were no significant traffic effects in March and April.
- Longitudinal cracking was related in the months of March and April to total vehicles per day, and ESALs per day for FHWA class 10. It was related to total empty trucks and AADTT of all empty trucks in May. Changes were also caused by FHWA class 6 empty in March, and FHWA class 6 loaded and FHWA class 8 empty in May.
- Rutting changes were significant with several traffic measures. With the exception of April, all FHWA class 10 measures (loaded, empty trucks, and ESALs per day) caused rutting changes. For class 9, ESALs per day caused rutting changes in both April and May. Other measures that caused changes in March included total trucks loaded and empty, and AADTT of loaded and empty trucks. Rutting changes in April were also related to FHWA Class 6 empty, and FHWA class 12 empty. Rutting changes were significant in May with total vehicles per day, FHWA class 6 loaded, FHWA class 8 empty, and FHWA class 12 empty.

7.9 FHWA Class 10 Impact Assessment

FHWA class 10 is of primary interest in this study since it contains the 98,000-lb 6-axle logging truck configuration. This particular class had a significant effect on changes from an average rut depth change of zero for both loaded and empty trucks (except loaded in April), and ESALs per day. There was no significant effect on alligator cracking but there was an impact on longitudinal cracking for two months of Spring Thaw (March and April) based on the ESALs per day.

To illustrate this effect, Figures 7.14 through 7.16 plot the daily number of loaded and empty 6-axle logging trucks (FHWA class 10) versus monthly rut depth changes. There was a negative change in rut depth for March and April, while a positive change occurred in May. The negative rut depth change may be explained by non-permanent deformation in the pavement profile as frost leaves the pavement base. Positive rut depth can be explained by permanent deformation from repeated vehicle loading. Changes in rut depth with no logging trucks (n=0) suggests that other vehicles are influencing rut depth. Overall, there was no discernible difference between loaded and empty 6-axle logging trucks, suggesting that loaded and empty logging trucks during spring thaw produce similar changes in rut depth.

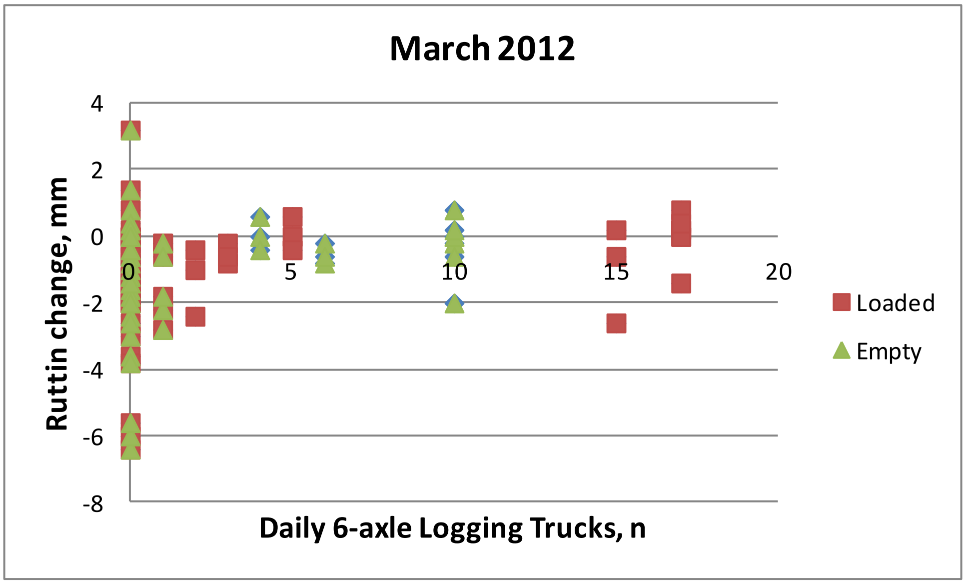


Figure 7.14 Rutting changes from Daily 6-axle Logging Trucks in March 2012

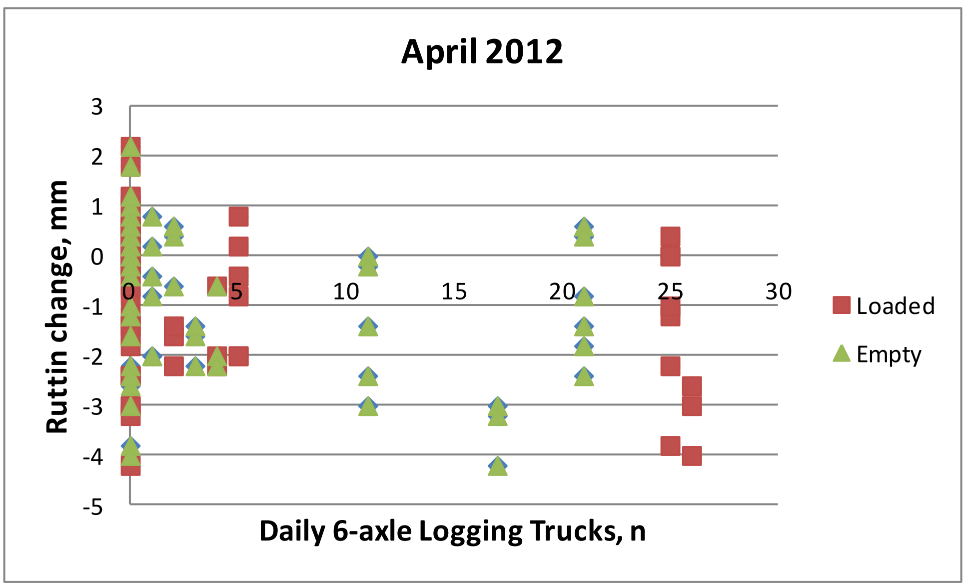


Figure 7.15 Rutting changes from Daily 6-axle Logging Trucks in April 2012

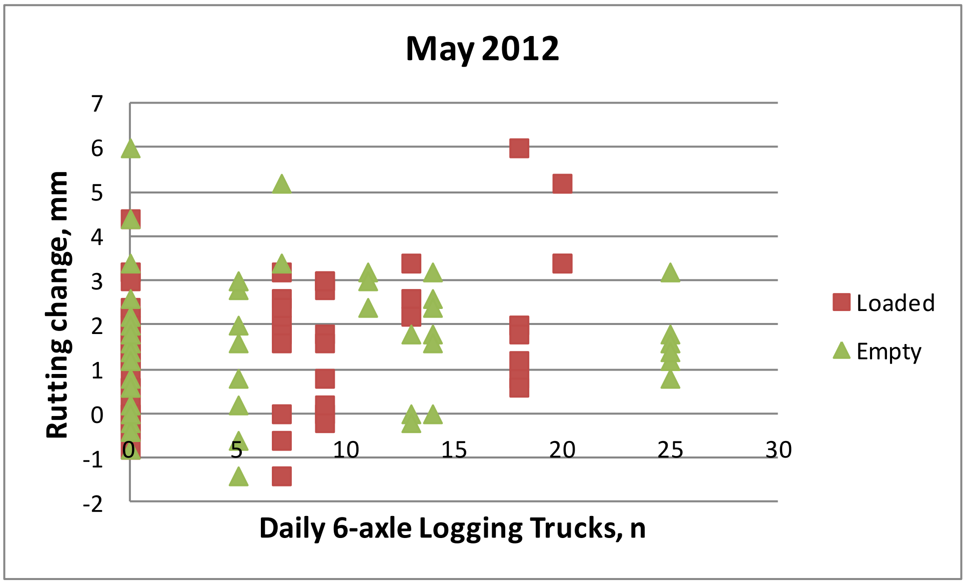


Figure 7.16 Rutting changes from Daily 6-axle Logging Trucks in May 2012

7.10 Summary

On a monthly basis from December 2011 to May 2012, manual pavement performance measurements were recorded for longitudinal cracking, alligator cracking, and rutting on 11 highway segments ranging from 1 to 19 years of age. Spring Thaw declaration in Zone 1 was on March 9, 2012. Data collection occurred 3 months before the declaration date (December, January, and February), and 3 months after the declaration data (March, April, and May). A summary of performance measurements and measurement frequency includes:

(1) Longitudinal cracking in the wheel path – monthly;
(2) Alligator cracking in the wheel path – monthly;
(3) Rutting in the wheel path – monthly; and
(4) Roughness - October 2011 and May/October 2012 only.

The following conclusions were reached from the data analysis:

Distress Trends

- In general over the six-month performance period, there was either an increase in distresses or no change in distresses for primarily new pavements. All six months were used to develop statistical linear regression lines including the three months during Frozen Road Declaration (December, January, and February) and three months after the Spring Thaw Declaration in Zone 1 on March 9, 2012 (March, April, and May). This approach permitted a balanced sample of both frozen and spring thaw data points to create trend lines.
- Superpave mix design segments ranging in age from 1 to 8 years exhibited low average rut depths (≤ 6 mm) compared to the older Marshall mix design segments (12-19 years old) which had depths ≤ 16.0 mm.
- All 7 Superpave mix design segments experienced no alligator cracking, while 3 of the 4 Marshall mix design segments initially had alligator cracking and experienced an increase from the beginning to the end of the study period.
- With the exception of one segment, Superpave segments experienced lower amounts of longitudinal cracking compared to the Marshall mix segments

Linear Models for Loaded 6-axle Logging Truck Traffic Lane

- Alligator cracking increased in 3 of 11 highway segments age 12 to 19 years that were originally constructed of Marshall mix design. Eight segments had no statistically significant slope with age 1 to 13 years; 7of the 8 segments were of Superpave mix design construction.

- Longitudinal cracking increased in 4 segments age 8 to 19 years; 3 of the 4 segments were of Marshall mix design construction. Seven segments had no statistically significant slope with age 1 to 12 years; 6 of the 7 segments were of Superpave mix design construction.
- Rutting increased in 3 segments with age 1 to 8 years; 1 segment had a decrease at age 19 years; 7 segments had no statistically significant slope age 1 to 13 years.
- Roughness increased in 3 of 9 segments age 1 to 7 years, with the IRI increasing at a monthly rate from 2 to 6 in/mile in the loaded lane and 2 to 5 in/mile in the empty lane; 6 of 9 segments had no statistically significant slope age 1 to 12 years.

Linear Models for Empty 6-axle Logging Truck Traffic Lane

- Alligator cracking increased in the same 3 segments as the loaded lane with age 12 to 19 years; 8 segments had no statistically significant slope age 1 to 13 years.
- Longitudinal cracking increased in 4 segments of which 3 were the same as the loaded lane with age 7 to 19 years; 7 segments had zero or no statistically significant slope with age 1 to 13 years.
- Rutting increased in 6 segments age 1 to 13 years; decreased in 3 segments age 1 to 13 years; 2 segments had no statistically significant slope with age 7 to 19 years.
- Roughness increased in 3 of 9 segments with age 2 to 7 years, and 2 segments had the same increase as loaded line; 6 of 9 segments had no statistically significant slope with age 1 to 12 years.

Comparison of Distress Rate Changes (Slopes) between Loaded and Empty Traffic Lanes

- Alligator cracking and longitudinal cracking slopes were significantly different on 1 of 11 segments age 13 years; no statistical slope difference on 10 of 11 segments age 1 to 19 years.
- Rutting slopes significantly different on 1 of 11 segments age 2 years; no statistical slope difference on 10 of 11 segments age 1 to 19 years.
- Ride (roughness) significantly different on 1 of 8 segments age 1 year; no statistical slope difference on 7 of 8 segments age 1 to 12 years.

Changes in Pavement Condition by Vehicle Class during Spring Thaw

- Alligator cracking changes were only related to total loaded trucks and AADTT of all loaded trucks, ESALs per day for FHWA class 10 in the month of May only. There were no significant traffic effects in March and April.
- Longitudinal cracking was related in the months of March and April to total vehicles per day and ESALs per day for FHWA class 10. It was related to total empty trucks and AADTT of all empty trucks in May. Changes were also caused by FHWA class 6 empty in March, and FHWA class 6 loaded and FHWA class 8 empty in May.

- Rutting changes were significant with several traffic measures. With the exception of April, all FHWA class 10 measures (loaded, empty trucks, and ESALs per day) caused rutting changes. For class 9, ESALs per day caused rutting changes in both April and May. Other measures that caused changes in March included total trucks loaded and empty, AADTT of loaded and empty trucks. Rutting changes in April were also related to FHWA Class 6 empty, and FHWA class 12 empty. Rutting changes were significant in May with total vehicles per day, FHWA class 6 loaded, FHWA class 8 empty, and FHWA class 12 empty.

Effect of FHWA Class 10 98,000-lb capacity 6-axle logging trucks during monthly Spring Thaw

- No significant effect on alligator and longitudinal cracking for all months of Spring Thaw.
- Loaded and empty 6-axle logging trucks during Spring Thaw produce similar changes in rut depth.

Chapter 8 – Conclusions and Recommendations

8.1 Summary and Conclusions

This report investigated the impact of a January 1, 2011 Wisconsin statutory change that allows vehicle combinations up to 98,000 lbs using 6 axles to transport loads of raw forest products during the spring-thaw suspension period. Prior to the statutory change, Wisconsin DOT could suspend overweight permits for the transportation of raw forest products during the spring thaw, or impose special weight limits on highways.

The specific goals of the investigation were to: (1) determine if there is an impact with this statutory change; (2) identify whether certain vehicle classes or categories are more damaging than others, and the possibility of lessening the impact of these heavy loads; (3) determine if certain pavements are impacted with increased loads due to policy change; (4) provide a means to identify key destinations/sources of raw forest products; and (5) present tools to help the Wisconsin DOT better forecast these impacts.

The goals of the research study were examined through a series of tasks including: a) review and synthesis of literature on spring load restriction practices with particular attention to the timing for restrictions and methods used, impact on performance, load restriction benefits, and practices in Wisconsin; b) review of logging industry truck hauling practices in Wisconsin through a survey and direct interviews with members of the Great Lakes Timber Professional Association (GLTPA), interview of Wisconsin DNR managers of forested lands, and interview of commercial land owners of forested property; and c) statistical analyses of traffic and distress data collected for a network of logging truck routes in northern Wisconsin from December 2011 to May 2012. On the basis of the study, the following summary and conclusions are provided.

8.1.1 Literature Review

The literature suggested that seasonal load restriction (SLR) practices are designed to control truck loading before and during spring thaw and inhibit premature damage and higher maintenance costs, as well as reduce economic activity. The following observations are made from the literature:

- In the U.S. and Canada, there has been a shift towards the use of a Cumulative Thawing Index approach and some deflection measurements to determine the start and end dates for SLR. A majority of states in freeze-thaw regions apply restrictions, where 24% use a quantitative method and 24% use a fixed-date method to impose restrictions. A majority of agencies use inspection and observation to remove restrictions with 29% imposing restrictions by date, and 14% use some type of quantitative method.
- Wisconsin DOT manages three distinct weight restriction programs applicable to the state highway system only and do not involve local county or township roads. The programs include:

(1) Frozen Road Declaration, (2) Class II roadway restrictions, and (3) springtime posted roads. The frozen road declaration dictates the winter weight limits on frozen roads. The average date for the beginning of the frozen road period in Wisconsin based on 27 years (1984-2011) of data occurs on December 22nd while the 27-year average date for ending the frozen road period is March 4th. The Class II Road program involves all state highways that are judged to have an unstable condition of the roadway subgrade during the period when frost is leaving the ground such that the travel of vehicles with overweight permits would cause undue damage to the highway. Wisconsin has determined that the 45-year average for imposing spring load restrictions begins on March 9th, while the 45-year average for ending the load restriction occurs on May 9th. The posted roads program is applicable to roadway sections that are considered too weak to even withstand the legal load limit of 80,000 pounds during the springtime freezing and thawing period. The posted road program goes into effect during the second week in March until late April or early May.

- Regarding the effect of weight restrictions on pavement life, a 2002 study in Minnesota reported that pavement life can be shortened by 4 to 8% if weight restriction is set a week too late, and reduced further to 5-12% if higher winter axle load premiums are removed a week too late. A 2000 study in Minnesota also estimated that a typical low-volume asphalt road life will be increased by about 10 percent when the procedure for placing and removing SLR used actual and forecasted average daily temperature. A 1990 Federal Highway Administration report concluded that reducing truck weights by 20% between late February and early May can increase the life of vulnerable pavements by 62%. In addition, a 50% reduction in the truck weight can result in a 95% increase in pavement life. A 2008 study in Alabama, outside the wet-freeze region of this study, demonstrated that changing rear 34,000-lb tandem axles to 51,000-lb tridem axles had no effect on pavement performance when the total weight of the traffic stream was held constant.
- Although SLR has been implemented for many years, very few studies have been conducted to examine the benefits and costs associated with SLR. A 2007 Minnesota study through a survey of industry costs, combined with pavement performance and freight demand models, concluded that the economic benefits without SLR to industry and haulers significantly outweighed the costs of marginally higher damage to local roads. A 2006 North Dakota economic analysis of increasing load limits concluded that the costs associated with eliminating seasonal limits far outweighed the benefits.
- A 2009 Wisconsin study, without directly considering seasonal load practices, concluded that 98,000-lb 6-axle semi-trailer generates the greatest savings in transport costs for the system user (private companies and individuals who use the Wisconsin highway system). The analysis also shows that savings would accrue to the public agencies in categories for pavement costs, safety, and congestion. Public agencies would not experience savings for structures, where the heavier truck configurations would require additional investment to replace, reinforce, or post some bridges.

8.1.2 Industry Data Collection

Data collected from sectors of the logging industry through surveys and direct interviews addressed several elements to broaden knowledge of logging practices, with the goal of assisting Wisconsin DOT to identify key destinations and sources of raw forest products. The elements included: General impact of SLR on logging operations (operating times, key sources and destination of raw forest products, routes, costs, firm size relationship with daily logging trips), and the short-term impacts of the new RS permit law. The interviews and survey revealed the following:

Great Lakes Timber Professional Association

- Nearly all GLTPA respondents (18 of 19, 95%) indicated changing routes during the SLR period and reducing load to comply with regulations. The combination of longer routes and vehicle changes prevent some 75% of haulers from hauling during the SLR period.
- A comparison between 2010 and 2011 found average logging trips generated per day increased from 12.8 to 13.0 trips/day. Average miles traveled during the SLR restriction period also increased between 2010 and 2011 from 23,127 miles to 28,354 miles. Average operating cost also increased from $1.75/mile to $1.83/mile, with no explicit reason given.
- Pricing at certain mills are a combined $/cord and $/mile, or $/ton.
- Logging season generally begins after the first frost in October when sap begins to run, and ends in March when it becomes difficult to drive in thawing soil. Monday through Friday hauling is common, while a few mills operate 24/7. Saturday operations are generally mulch or chips from logging during the weekdays.
- Load limits vary among counties and roadways presenting a challenge for routing logging trucks. Border hauling from Wisconsin to Michigan (or back) presents a permit challenge, where hauling from Wisconsin to Michigan requires one plate, and hauling from Michigan to Wisconsin requires two plates. Michigan log haulers generally do not want to travel into Wisconsin with additional restrictions.
- Seasonal variations affect where the wood is harvested in Wisconsin. Areas with heavier soils allow for more flexibility in the haul routes as the logging companies will have a greater selection of routes to choose from during Spring Thaw. Tree species is an important factor in the determination of destinations and sources for the raw forest products. With 23 commercial types of trees in Wisconsin forests, the logging companies are drawn to the wood necessary for their products. Based on productivity guidelines (Managed Forest Lands regulations), the rotation age for most hardwoods (including Red Pine) is at least 60 years.

Paper Mill Companies

Destinations of haul trucks were obtained through meetings with four large paper mill companies in the state. The meetings revealed the following:

- The primary destination of loaded log trucks are pulp, paper, and saw mills within the state and along the Michigan and Minnesota borders.

- There are a total of 56 pulp and paper mills, and over 300 sawmills in the state. Other destinations include landings and railroad loadout facilities. Some rail shipments are sent to Canada, Tennessee, or Virginia.
- Numerous mills are located in regions with high-end pavement designs, in particular PCC pavements. These locations are primarily in the Chippewa and Fox River Valleys.
- Railroad sidings and landings are important generators of logging truck trips. NewPage Corporation operates several large landings in northern Wisconsin, while Domtar Industries and Thilmany Papers favor railroad sidings to transport logs to mills in the Wisconsin River Valley and Fox River Valley, respectively.

8.1.3 Management of Forested Land

The Forestry Division of the Wisconsin DNR provided the most available recent data (2008) at the time of the study regarding public lands designated for logging, as well as the harvest volumes and directional distribution of logs in Wisconsin. Analysis of the data indicated the following:

- 250 million cubic feet of roundwood was harvested in Wisconsin in 2008.
- Six counties accounted for 73% of the in-take of the roundwood. Wood County received approximately 35% of the total roundwood harvested in Wisconsin (some via rail) while the remaining counties are Lincoln, Marathon, Price, Sawyer, and Outagamie Counties.

8.1.4 Highway Selection and Field Data collection

A comprehensive database was created for all pavement segments in the state under Wisconsin DOT management for the purpose of selecting appropriate segments for field data evaluation. The selection was based on a wide range of factors including: Highways operating 98,000-lb log loads during the spring thaw season, known destination of the loaded log trucks, known direction of loaded and empty log trucks on a given highway, two-lane highways to channel truck traffic to a single directional lane, cooperation by weigh scale operators to collect data, asphalt pavement (not concrete), emphasis on northern logging regions of the state, multiple destinations in a concentrated area to increase data collection productivity, and proximity of the sections to forests damaged by a July 1, 2011 severe thunderstorms in northwest Wisconsin. The process resulted in two logging truck route clusters (made up of eleven segments). One cluster of the routes located in Sawyer and Rusk counties included STH 40, STH 48, STH 27, and STH 27/70. The other cluster involved STH 77 in Burnett and Washburn counties.

Field data collection involving traffic counts, log truck weight data, and pavement condition measurements were performed at the two logging truck route clusters (made up of 11 segments) on a monthly basis between December 2011 and May 2012. Wisconsin DOT performed IRI and rut measurements of the chosen destination segments before the Frozen Road Declaration in October 2011 and after the Spring Thaw Suspension Period in May 2012.

A primary objective of obtaining traffic counts was to estimate the volume by truck classification of loaded and empty logging trucks in order to determine truck class impact on pavement deterioration. The traffic counts were performed using Trax Flex HS™ automatic traffic data recorders to capture bi-directional vehicle classification data on the highway segments. There was near certainty that snowplowing operations would temporarily force removal of the traffic counter tubes from the pavement, therefore, two radar recorders were mounted at two control count stations to ensure continuous traffic measurement. To distinguish between logging trucks (loaded or empty) and all other trucks, visual sampling counts were performed daily at each control station in the morning and afternoon and for specific days at coverage stations. The visual data were used in conjunction with volume data from the automatic traffic recorder to estimate the logging truck volume for each segment.

Log truck weight data were collected from platform scales at the entry to log destinations in the vicinity of the 11 highway segments evaluated in this study. Individual axle weight and axle spacing data were collected monthly before and after the spring thaw suspension period at four weigh scales in the study region. The purpose was to determine the actual axle load and gross vehicle weight distributions for various truck axle configurations to examine their potential effect on pavement performance. In addition to the data obtained by the research team, operators of two scales in the vicinity of the study area provided monthly weight reports for log trucks that entered and exited the wood yard.

Monthly manual pavement performance data collected included longitudinal cracking, alligator cracking, and rutting. Additionally, Wisconsin DOT also performed IRI and rut measurements of the chosen highway segments in October 2011 (before the Frozen Road Declaration) and in May 2012 (after the Spring Thaw Suspension Period).

On the basis of the analyses of the traffic, log truck weight, and performance data, several observations and conclusions are drawn in the following areas:

8.1.5 Traffic Counts

- FHWA vehicle classes 9 and 10 are the main carriers of logs throughout the studied network. The observed class 10 consists of two truck configurations each with 6 axles except that one has a single 3-axle trailer and the other a single 2-axle "pup" trailer. The Class 9 is an "18 wheel" semi-truck with variable trailer axle spacing.
- There is a general increase in loaded logging truck traffic during the winter months with peaking occurring mostly in December or February along the studied network. There is a significant decline of loaded logging trucks in March, which seems to support logging truckers' assertion from the survey that they either quit running or change routes to comply with spring load restrictions.
- For the majority of the network, loaded logging truck movements peaked in one direction, while empty logging truck movements peaked in the opposite direction.
- The Northbound direction of STH 27 (between STH 70 Stone Lake and Hayward) carried more trucks loaded with logs in the winter (Dec. 2011-Feb. 2012) than in spring (March-May) with the peak log truck volume occurring in February at 63 trucks/day and dropping to 4 trucks/day in March. The number of loaded logging trucks in February in the NB direction was approximately

eight times that in the SB direction. The total empty logging truck volume in the SB direction was about double that in the NB direction. Logs were predominantly carried by FHWA truck classes 9 and 10. The two vehicle classes represented nearly 100% (61/63) of all the log truck volume per day in the NB direction during the peak month. In the SB direction, the peak period occurred in January and the two vehicle classes again represented nearly 100% (13/14) of all loaded log truck volumes per day.

- Along STH 77 west of Minong between CTH H and USH 53, loaded truck movements occurred only in the EB direction from January to May, while empty truck movements occurred only in the WB direction for the same period. In other words, there were no WB loaded trucks and no EB empty trucks on this pavement segment. Peak loading occurred in February and April at a rate of 32 trucks/day but dropped to zero in March. The peak for empty logging trucks occurred in February with the minimum occurring in March. FHWA classes 9 and 10 were the main carriers of logs. Class 9 carried more logs during the peak month of February compared to class 10.
- For the segment of STH 77 east of Minong between USH 53 and CTH M, peak loading occurred in January for both directions but with higher volume of 51 trucks/day in the EB direction compared to 28 trucks/day for the WB. Loading activity stopped in March for the WB direction but continued throughout the entire study period for the EB, which registered a minimum of 19 trucks/day. FHWA vehicle classes 9 and 10 were the main carriers of logs predominantly in the EB direction. Vehicle class 10 however, delivered the bulk of loaded log truck trips per day throughout the study period.
- For the portion of STH 27/70 (Radisson to Ojibwa), there were twice as many loaded trucks in the EB direction as in the WB direction during the study period. However, during the same period there were more empty trucks in the WB direction than in the EB direction. The EB loading peaked in December at a rate of 54 trucks/day and dropped to one truck/day in March, with FHWA classes 9 and 10 represented 87% of the loaded truck volume in December. The WB loading peaked in February at a rate of 32 trucks/day and dropped to 4 trucks/day in March.
- Along STH 27 (between Ojibwa and Ladysmith), loaded logging truck movement was predominantly SB with a peak average of 23 loaded trucks per day in December and February, then dwindling to 3 per day in March. February was the only month that loading activity occurred in the NB direction with six loaded trucks per day. Classes 9 and 10 carried nearly 100% of the daily loaded trucks in the SB direction during the study period.
- For the segment of STH 48 between West County line and STH 40/CTH D, loaded logging truck activity occurred in the EB direction for December only, averaging 21 trucks per day. No loaded logging truck activity occurred in the WB direction during the entire study period. Empty logging trucks were observed in both directions for December, with the higher volume (9 trucks per day) occuring in the WB direction.Classes 8, 9, 10, and 12 were carriers of logs in the EB direction in December. Class 9 carried the largest share of nine trucks/day followed by class 12 with six daily trucks. Empty logging truck traffic was dominated by class 9 in both directions.
- For the STH 40 portion between Becky Creek and North County Line, the largest combined loaded truck volume (13 trucks/day) was recorded in December, but for the SB direction only. The NB direction had 3 trucks/day but only for February. Class 10 trucks carried logs in the NB direction but only for February, at a rate of 3 trucks/day. For the SB direction, classes 8 and 9 carried logs at a combined rate of 13 trucks/day, with class 9 carrying 85% (11/13) of the volume.

There were no empty truck movements in the SB direction during the entire study period, except during February.

- Along STH 40 between Exeland and Radisson (STH 48 – STH 27/70), Loaded logging truck movement occurred only in the NB direction during the entire study period with peak loading volume (six trucks/day) occurring in December. Empty logging truck volumes for the NB varied considerably during the study period. The SB attracted a high empty volume of 26 trucks per day for December and no more for the remainder of the study period. All December loadings were carried by class 9 trucks, while January and March loadings were carried by classes 10 and 6, respectively. March loading was 3 trucks/day.

8.1.6 Log Truck Weight

- Measurements taken at the platform scales by the research team, coupled with monthly loading reports received from operators of two scales in the study area suggest violations of GVW and axle spectra load limits. During the winter (Dec-Feb), 17.5% (7/40) of loaded FHWA class 10 trucks exceeded the maximum 98,000 lbs GVW limit by an average of 1,620 lbs, while 14.6% (6/41) exceeded the limit by an average of 1,643 lbs in the spring (Mar-May). The monthly scale reports for a sample of truck weights exceeding 90,000 lbs indicated an average of 31.3% and 24% GVW violations at the two operators' scales during the winter, and 25.3% and 32.7% violations during the spring.
- Although there are a considerable proportion of overloaded trucks, the magnitude of the average overload is less than 5% of the maximum 98,000-lb legal limit.
- Per Wisconsin Statute s.348.15(br), the single axle load is limited to 23,000 lbs, while the load on a tandem axle is limited to 38,000-lb during frozen road conditions for vehicles or combination of vehicles that transport peeled or unpeeled forest products cut crosswise on Class A highways and have axle spacing 8 or less feet. Any other time of the year, the numbers reduce to 21,500 lbs and 37,000 lbs, respectively, for single and tandem axles. The results of the loading analysis indicate that class 10 single-axle load exceeded legal limits for both frozen and non-frozen road conditions. For tandem axles, approximately 12% (4 of 33 axles) exceeded the 38,000-lb limit for frozen roads by an average of 2,910 lbs during the winter. During the spring, approximately 11% (4 of 36 axles) exceeded the 37,000-lb limit by an average of 565 lbs. Per Wisconsin Statute, s.348.175(br), the allowable load limit for tridem axles with spacing in the range of 9-10 feet corresponds to a load range of 55,000-55,500 lbs for frozen Class A highways. None of the observed loads violated the tridem axle load limit during the winter months. During any other time of the year, Wisconsin Statute, s.348.15(br) indicates that for groups of three or more consecutive axles more than 9 feet apart, an additional 4,000 lbs is usually allowed, depending on the distance between foremost and rearmost axles in a group. The observed tridem axle spacing was 10 feet, which corresponds to a load of 47,500 lbs. Approximately 37% (13/35) of tridem axles were in violation of the specified limit.
- No FHWA class 9 trucks measured at the platform scales violated the 23,000-lb legal limit set for single axles for frozen roads during the winter (Dec-Feb). During the same period however, 22% (2 out 9) of axles violated the 38,000-lb limit for tandem axles with spacing in the range of 4-7 feet by an average of 570 lbs.

- During the spring, 4.5% (1 of 22 axles) of class 9 trucks were in violation of the single axle load limit by 3,800 lbs. On the tandem axle side, 8.3% (2 of 24) exceeded the 37,000-lb limit by an average of 4,125 lbs.
- The ESAL factor for class 10 log loaded trucks was estimated to be 2.66 for axle loads averaging 14,085 lbs on single axles, 34,615 lbs on tandem axles, and 46,770 lbs on tridem axles. The ESAL factor for class 9 log loaded trucks was 3.27 for axle loads averaging 15,835 lbs on single axles and 33,290 lbs on tandem axles.
- On the basis of the ESAL factor estimates and average log loads, it was deduced that the relative-log carrying efficiency (with reference to the pavement damage caused) of class 10 trucks averages approximately 22,000 lbs/ESAL compared to 15,400 lbs/ESAL for class 9 trucks.

8.1.7 Pavement Performance

On a monthly basis from December 2011 to May 2012, manual pavement performance measurements were recorded for longitudinal cracking, alligator cracking, and rutting for 11 highway segments in opposing lanes; one opposing lane was designated as the "loaded" lane and the other as the "empty" lane.

Analyses of the pavement conditions regarding the loaded and empty lanes for the segments indicate that:

- None of the seven segments (ranging in age from 1 to 8 years) with Superpave mix design surfaces experienced alligator cracking. Three out of four Marshall mix design surfaced segments ranging in age from 12 to 19 years experienced significant alligator cracking. The same seven Superpave mix design segments exhibited low average rut depths (≤ 6mm) compared to the older Marshall mix design segments which had depths ≤ 16.0 mm.
- Only one segment at age 13 years showed any changes in alligator cracking and longitudinal cracking differences between the loaded and empty lanes. The remaining 10 segments ranging in age from 1 to 10 years did not.
- Another segment at age 2 years showed differences in rutting between loaded and empty lanes; the rest of the segments ranging in age from 1 to 19 years did not.
- Ride (roughness) was only significantly different on 1 of 8 segments at age 1 year; no differences were found for 7 of 8 segments with age ranging from 1 to 12 years.
- Loaded and empty 6-axle logging trucks during Spring Thaw produce similar changes in rut depth.

8.2 Recommendations

A systematic approach was employed to examine the impact of a January 1, 2011 Wisconsin statutory change that allows vehicle combinations up to 98,000 pounds using 6 axles to transport loads of raw forest products during the spring-thaw suspension period. The impact was evaluated by comparing spring-thaw distress changes associated with adjoining opposing pavement lanes for eleven highway segments that carry log loads predominantly in one direction (loaded lane) and returning predominantly empty in the opposite direction (empty lane). Based on the findings of the study, the following recommendations are made:

- A major objective of this study was to determine if certain pavements are impacted by increased loads due to the RS permit law. A total of eleven pavement segments were analyzed in the study and fell into two paved surface categories: older Marshall mix design (4 segments) and newer Superpave mix design (7 segments). The analyses showed that the Superpave mix design segments generally produced better performance than the Marshall mix design segments. During both winter and spring, higher mean levels of alligator cracking and rutting were associated with the Marshall mix segments compared to the Superpave segments. Mean levels of longitudinal cracking were however, not significantly different between the two mix types. A segment by segment analysis also revealed that one Marshall mix segment (age 13 years) exhibited significantly higher rates of progression in alligator and longitudinal cracking in the loaded lane when compared to the adjoining empty lane. Hence, the rehabilitation or replacement of older Marshall segments (which are already nearing their terminal lives) within the logging route network is needed to allow up to 98,000lbs of raw forest products to be transported on six-axle vehicles, while inflicting lesser damage to the pavement network. In addition, this study was conducted one year after the implementation of the RS permit law for a small number of segments; a longer time frame and many more segments may be needed to help evaluate the overall long-term impacts from log loaded trucks, or a field test consisting of a special test section could be constructed and subject to the RS permit law trucks to capture their overall impact during the spring-thaw season.
- To identify whether certain vehicle classes are more damaging than others, the ESAL factor estimates in this study suggest that class 9 log loaded trucks with an ESAL factor of 3.27 creates more damage than class 10 loaded trucks with an ESAL factor of 2.66. In addition, the class 9 results in a lower relative-log carrying efficiency of 15,400 lbs/ESAL compared to 22,000 lbs/ESAL for the class 10. It is recommended that Wisconsin DOT coordinate with the logging industry to promote the use of vehicle classes (such as the class 10), which yield higher relative-log carrying efficiencies. Such practices will lessen the damaging effect, especially along portions of the logging route network with inferior paved surfaces originally designed using the Marshall mix design method.
- With all other factors (besides traffic) controlled such as in this study, deterioration of pavements is a contribution from all vehicle types and not only log-related trucks. The study could be extended to capture the damage contribution by truck categories that carry other heavy commodities during the spring-thaw season across the same routes used by logging trucks. In this way, relative-load carrying efficiencies with reference to the pavement damage caused can be established across the different truck categories based on the amount and type of heavy commodity carried. This input can be part of any comprehensive and efficient approach for the recovery of pavement damage costs from individual heavy commodity trucks (HCTs). In addition, such a study will provide improved information on where and how much HCT-related damage is occurring around the network to determine maintenance activities, improve loading practices such as reduced axle and GVW, as well as encourage the use of a more pavement-friendly fleet of HCTs with characteristics such as an increase in the number of axles per vehicle.
- The study found a considerable proportion of trucks to be overloaded, but the average magnitude of the overload was less than 5% of the 98,000-lb maximum GVW limit permitted under the RS permit law. It is recommended that Wisconsin DOT coordinate with the logging industry to

immediately address the problem before overload magnitudes become excessive and create unwarranted damages to the pavements.

- To provide a means to identify key origins/destinations for forest products, as well as tools to help the Department better forecast impacts, it is recommended that Wisconsin DOT build upon the GIS analyses files developed in this study that showed the locations of mills in the state, probable logging routes, and the six counties in the state that have high-demand for roundwood. In addition, a close working relationship with the Forestry Division of the Wisconsin DNR that provide information regarding public lands designated for logging, as well as the harvest volumes is recommended.

References

American Association of State Highway and Transportation Officials. (2001). *Guide for Vehicle Weights and Dimensions.* Washington, DC.

Bradley, A. (2006). "Hauling with Full Axle Weights and Reduced Tire Pressures on Weight-Restricted Roads in British Columbia", Technical Report, 2006.

Cambridge Systematics, Inc. (2009). "Wisconsin Truck Size and Weight Study", Wisconsin Department of Transportation, Madison, WI, June 15, 2009.

Canadian Strategic Highway Research Program (2000). "Seasonal Load Restrictions in Canada and Around the World," C-SHRP Technical Brief # 21, http://www.cshrp.org/products/brief-21.pdf, September 2000.

Center for Paper Business and Industry Studies (2011). "Pulp Mills, Pulp&Paper Mills, Paper Mills in Wisconsin", <http://www.paperstudies.org/millsonline/wisconsin.php>, (Oct. 12, 2011).

Deacon, J.A., (1969). "Load Equivalency in Flexible Pavements," Proceedings, Association of Asphalt Paving Technologies, Vol. 38, pp. 465-491.

Federal Highway Administration (1990). "Spring Use Restrictions", Pavement Newsletter No. 17/1990, U.S. Department of Transportation, Washington, D.C., 1990.

Huang, Y.H. (2004). *Pavement Analysis and Design.* 2nd ed. Pearson–Prentice Hall, Upper Saddle River, NJ.

Huen, K., Tighe, S., Mills, B., and Perchanok, M. (2006). "Development of Tools for Improved Spring Load Restriction Policies in Ontario", *Proceedings of the Annual Conference of the Transportation Association of Canada*, Charlottetown, Prince Edward Island, 2006.

Janoo, V. and Cortez, E. (2002). "Pavement Evaluation in Cold Regions", *Proceedings of the 11th Cold Regions Engineering International Conference*, Anchorage, Alaska.

Kestler, M., Berg, R.L. and Bigl, S.R. (2011). "Statistical Significance of Freeze-Thaw Related Factors on Cumulative Damage to Flexible Pavements" Proceedings of the 2011 Transportation Research Board Annual Meeting, Washington, D.C., January 22-26, 2011.

Kestler, M.A., Knight, T., and Krat, A.S. (2000). "Thaw Weakening and Load Restriction Practices on Low Volume Roads", Technical Report ERDC/CRREL TR-00, US Army Corps of Engineers Engineer Research and Development Center, June 2000,

Kestler, M.A., Knight, T., and Krat, A.S. (1998). "Thaw Weakening on Low Volume Roads and Load Restriction Practices", *Proceedings of the 1998 Transportation Research Board Annual Meeting*, January 1998.

Leong, P., Tighe, S., and Doré, G. (2005). "Using LTPP Data to Develop Spring Load Restrictions: A Pilot Study", Paper submitted to AISIM, Waterloo, Canada, 2005.

Liu, Q., Kavanagh, L., and Shalaby, A. (2011). "Impacts of Reduced Tire Pressure on Strain Response of Thaw-Weakened, Low-volume Roads in Manitoba", *Journal of the Transportation Research Board*, No. 2203, Vol.1, pp 186-193, Transportation Research Board, Washington, D.C., 2011.

MacLeod, D., Palsat, D., and Clayton, A. (2002). "Rationalization and Harmonization of Spring Weight Restrictions and Winter Premiums for Roads in the Prairie Region of Western Canada", *Proceedings of the 2002 Annual Conference of the Transportation Association of Canada*. Winnipeg, Manitoba.

Minnesota DOT (2011). "Historical Spring Load Restriction Placement/Removal Dates", <http://www.mrr.dot.state.mn.us/research/seasonal_load_limits/thawindex/historical_slr_placement_dates.pdf> (Sept. 15, 2011).

Ovik, J.M, Siekmeier, J.A., Van Deusen, D.A. (2000). "Improved Spring Load Restriction Guidelines Using Mechanistic Analysis", Minnesota Department of Transportation, Maplewood, MN, 2000.

PAD-US (2011). "Protected Area Database of the United States", United States Geological Survey Gap Analysis Program, <http://www.protectedlands.net/padus/>, (Oct. 31, 2011).

Peters, K.D. and Timm, D.H. (2008). "Effects of Increasing Truck Weight Limit on Highway Infrastructure Damage," *Proceedings of the International Conference on Heavy Vehicles*, Paris, France, 2008.

Raad, L., Coetzee, N., and Hicks, G., "Load Restriction Criteria for Alaskan Roads-Phase 1: General Considerations and Field Studies", Alaska Dept. of Transportation and Public Facilities, Report No. SPR-UAF-92-07, 1995

Roess, R.P., Prassas, E.S., and McShane, W.R. (2011). "Traffic Engineering", fourth edition, Pearson Higher Education Inc., Upper Saddle River, New Jersey.

Saarenkento, T., and Aho, S. (2006). "Design and Repair of Roads Suffering Spring Thaw Weakening", ROADEX II Project, RoadScanners, 2006.

Smalski, B., Li, N., Levinson, D. (2006). "Economic Effects of Lifting the Spring Load Restriction Policy in Minnesota", Journal of the Transportation Research Forum, Volume 45 (2), pp. 45-56, 2006.

Stewart, R., Lautala, P. Ogard, L., Cao, M., Paterson, K., Graman, G., and Hicks, J. (2010). "Study of Greenhouse Gas Savings Associated with Congestion Reduction Using Multi-Modal Optimization of Timber Shipments in the North Central United States", Report DTOS59-08-G-00106, U.S. Department of Transportation, Washington, DC, April 2010.

Tolliver, D., and Dybing, A. (2007). "Impacts of Transportation Infrastructure on the Economy of North Dakota", Report to the North Dakota Legislative Council, Upper Great Plains Transportation Institute, Bismarck, ND, 2007.

Utterback, P., Moore, T.L., Kestler, M., and Affleck, R. (1995) “The Effects of Winter Haul On Low Volume Forest Development Roads", U.S. Dept of Agriculture, Forest Service, Technology and Development Program, 1995.

Wisconsin DNR (2011). "Wisconsin’s Primary and Secondary Wood Using Industry Databases", Department of Forest Ecology and Management, University of Wisconsin-Madison, < http://www.woodindustry.forest.wisc.edu>, (Oct. 12, 2011).

Wisconsin DOT (2011a). “Seasonal Load Limits Boundaries”, <http://www.dot.wisconsin.gov/travel/truck/docs/frozenroadmap.pdf> (Sept. 15, 2011).

Wisconsin DOT (2011b). “Frozen Road Declaration, Midseason Thaw, Ending the Declaration, and Spring Weight Restriction Decision Process,” <www.dot.wisconsin.gov/travel/truck/docs/whenisitfrozen.pdf> (Aug. 25, 2011).

Wisconsin DOT (2011c). “Frozen Road Declaration History”, <http://www.dot.wisconsin.gov/travel/truck/docs/frozenroadhistory.pdf> (Aug. 25, 2011).

Wisconsin DOT (2011d). “Winter (frozen road) Weights”, <http://www.dot.wisconsin.gov/travel/truck/docs/maximumweightlimits.pdf> (Sept. 15, 2011).

Wisconsin DOT (2011e). “Map-Class II Roads” <http://www.dot.wisconsin.gov/travel/truck/docs/class2roadwaymap.pdf> (Sept. 15, 2011).

Wisconsin DOT (2011f). “Springtime Posted Roads”, <http://www.dot.wisconsin.gov/travel/truck/docs/postedroadsmap.pdf> (Sept. 15, 2011).

Wisconsin DOT (2011g). “2009/2010 Wisconsin Vehicle Classification Data”, Division of Transportation Investment Management, Bureau of Highway Programs, Madison, WI.

Wisconsin Department of Transportation (2011). “2010 Wisconsin Continuous Count Data”, Division of Transportation Investment Management, Bureau of Highway Programs, Madison, WI.

Appendix

LOGGING TRUCK OPERATIONS SURVEY QUESTIONNAIRE

LOGGING TRUCK OPERATIONS SURVEY QUESTIONNAIRE

Dear Sir/Madam:

The Great Lakes Timber Professionals Association in conjunction with the Wisconsin Department of Transportation and University of Wisconsin - Platteville is evaluating the impacts of allowing heavier log loads in Northern Wisconsin during Spring Thaw. The research team will be very grateful if you could complete this survey questionnaire and return it to the address below. All company names and contact information will be strictly confidential and not shared with any other organization or entity. The success of this study in part depends upon your input. Upon completion of the study, an email link to the final report will be sent to you. Thank you for your participation.

Name of Organization: ____

Address: ____

City: ______________________ **State:** _____________ **Zip:** ___________

Questionnaire completed by: ______________________________________

Position /Title: ______________________________________

Telephone: ______________________________________

Fax: ______________________________________

e-mail: ______________________________________

RETURN QUESTIONNAIRE AND SUPPORTING DOCUMENTS **BY SEPTEMBER 30, 2011**

Dr. Sam Owusu-Ababio, P.E.
University of Wisconsin - Platteville
Dept. of Civil & Environmental Engineering
136 Ottensman Hall
Platteville, WI 53818
For questions contact him by phone: 608-342-1554; fax: 608-342-1566; e-mail: owusu@uwplatt.edu

Part 1. Company Size and General Truck Information

1. What size trucks does your firm use for transporting logs? (*Mark all that apply and indicate number of such trucks operated by your firm)*

___ 3-axle (#____) ____ 4-axle (#____) ___ 5-axle (#____) ___6-axle (#____)
___ 7-axle (#____) ____ 8-axle (#____) ___ Other
(Specify____)

2. What is the total number of truck drivers in your firm? _____________
3. What is the total number of employees in your firm? _____________
4. What is the total facility square footage of your firm? _____________ Please provide breakdown:
__________Office sf ___________ Warehouse sf ___________Other sf
(Specify_____________________________)

Part 2. Logging Truck Routing and Volume Information

1. Who determines the routes to be taken by drivers in transporting logs to desired destinations? *(Mark all that apply*).

____ Driver _____Dispatcher _____Other (Specify
_______________________________________)

2. In what ways do spring load restrictions affect your firm's operations? *(Mark all that apply)*
_____Change routes _____Reduce load magnitude _____Increase the number of trucks
_____Change vehicle types _____Other
(Specify____)

3. Please complete the table below relating to the logging truck trips generated by your firm during the Spring Thaw (March 1 through June 1). A trip is a truck carrying a load from an origin to a destination.

Season Year	Total logging truck trips produced by firm	Percent of firm's total truck trips that originated from Northern Wisconsin (see map)	Percent of firms total truck trips that originated somewhere else but terminated in Northern Wisconsin	Percent of total truck trips that passed through Northern Wisconsin with origin and destination outside Northern Wisconsin
Spring 2010				
Spring 2011				

4. Complete the table below for the truck miles traveled by logging trucks.

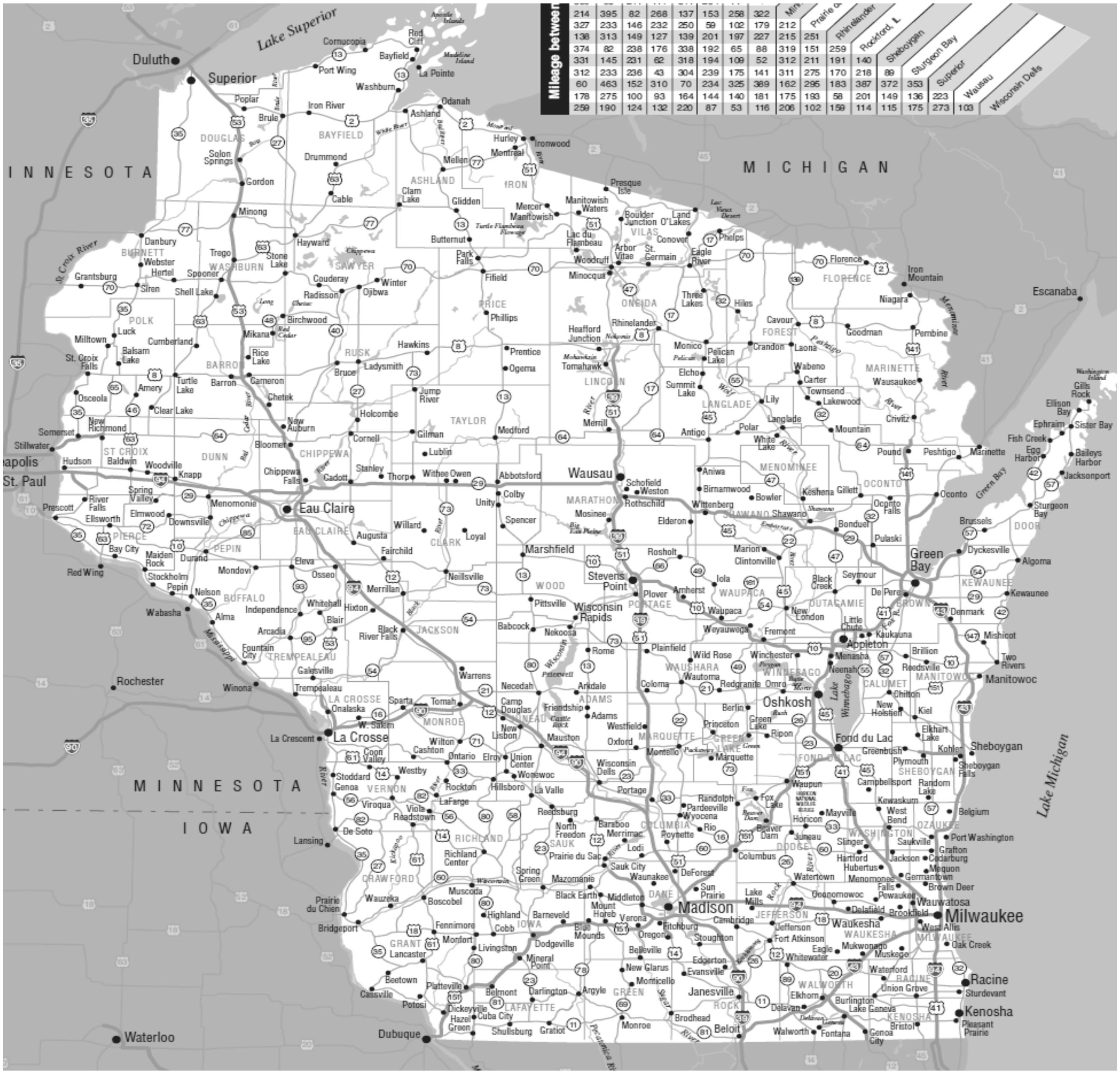
Season/Year	Total logging truck miles traveled	Total miles along spring load restriction roadways	Cost per mile to operate all logging trucks
Spring 2010			
Spring 2011			

5. On the map below, sketch the routing of your 5 most common trips driven in Spring 2010 in Northern Wisconsin. Sketch START for the originating point, solid arrow ⟶ for the haul route, END for the destination point, and solid arrow ⟶ for the return empty route. If you choose not to use the map, please list the 5 most common routings.

6. On the same map below, sketch the routing of your 5 most common trips driven in Spring 2011 in Northern Wisconsin. Sketch START for the originating point, dashed arrow ····➔ for the haul route, END for the destination point, and a dashed arrow ····➔ for the return empty route. If you choose not to use the map, list the 5 most common routings.

SOLID LINE for Spring 2010 START ⟶ END ⟶ START

DASHED LINE for Spring 2011 START ····➔ END ····➔ START



Your input is valued and greatly appreciated. ***Thank you.***