Evaluation of the Montana DOT
STATE TRUCK ACTIVITIES REPORTING SYSTEM (STARS)
Addendum (FY 04-05)

by

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EXECUTIVE SUMMARY

Since its implementation approximately five years ago, the Montana Department of Transportation (MDT) has been collecting data on commercial vehicle operations on the state's highways using the State Truck Activities Reporting System (STARS). This system consists of a statewide network of weigh-in-motion (WIM) sensors that collect data to support a variety of MDT's activities, from planning, to pavement design, to vehicle weight enforcement. Relative to this latter task, data from STARS is being used to characterize the overweight vehicle operations on the state's highway network throughout the year. This information is obtained by processing the STARS data using a software program (referred to as the Measure of Enforcement Activity Reporting System (MEARS)) developed by the Motor Carrier Services Division of MDT for this purpose.

The Motor Carrier Services Division of MDT has subsequently been actively investigating how the data provided by STARS and processed by MEARS can best be used to improve the effectiveness and efficiency of their weight enforcement efforts. This work began with a pilot program at the inception of STARS in which MEARS was used to identify those locations and times during the year when the greatest overweight problems historically occurred. Enforcement activities were then focused on these problem locations and times. It was found that overweight vehicle operations decreased as a result of this effort by approximately 20 percent, and that cost to benefit ratio of the pilot program (where the benefit resulted from a reduction in the pavement damage caused by overweight vehicles) exceeded 6.0.

Notwithstanding its early success, several features of STARS and its use in weight enforcement have been identified during and since the pilot program that merit further investigation. Note that STARS is a relatively new and innovative program, and little guidance is available from elsewhere regarding its use. Thus, the purpose of this project was to continue developing STARS as a tool for improving the effectiveness and efficiency of the state's weight enforcement efforts, with the intent of continuing to move forward from a pilot program mode of operation to a routine production mode of operation.

A continuing concern with the information provided by MEARS on overweight vehicle operations has been the appropriate identification and treatment of those vehicles in the traffic stream that are over standard weight limits but that are nonetheless operating legally. Such vehicles typically fall in one of three categories,

(1) vehicles that satisfy the Federal bridge formula and all axle weight limits but exceed the gross weight limit set in MEARS for a "typical" vehicle of that configuration,
(2) vehicles that only nominally exceed maximum weight limits, and
(3) vehicles that are permitted to operate over standard weight limits.

Presently, these vehicles are simply classified as overweight vehicles by MEARS, which can distort the number of overweight vehicles reported to be operating in the traffic stream.

In this project, factors were determined to adjust the output from MEARS to account for the presence of these vehicles in the traffic stream. These factors were developed at various sites and times from the overweight vehicle profiles determined by MEARS during enforcement

activities. This approach assumes that the vehicles that operate during overt enforcement activities are compliant with weight limits. Thus, any vehicles identified as "overweight" by MEARS during an enforcement activity must fall in one of the three categories listed above. Following this approach, adjustment factors were calculated by vehicle configuration, site, and system of the highway network. Aggregated across the sample of 9 sites used in this analysis, an average of 6.8 percent of the commercial vehicles were found to be compliant but over standard weight limits. As may be obvious, this value varied considerably with vehicle configuration, with the highest values of 63, 60, and 22 percent being observed for Class 10-3, 7-2, and 7-1 vehicles, respectively. This value also varied significantly by system of the highway network, with values of 10.3, 5.1, 7.4, and 5.7 percent being calculated for the secondary, primary, non-Interstate NHS, and Interstate systems, respectively. Adjustment factors were also determined relative to the pavement damage caused by compliant but over standard weight vehicles, in terms of excess ESALs/veh in the traffic stream. While average correction factors were calculated by system that can be used across all the STARS sites, these factors were found to vary sufficiently by site and time-of-year that they should be determined and applied in as much detail as is possible. While the process used to calculate these factors is analytically intensive, it may be possible to automate it, as much of the information required to support the calculations is already available through MEARS.

A primary consequence of overweight vehicle operations is accelerated pavement deterioration. MEARS quantifies pavement deterioration in terms of the excess ESAL-miles of travel caused by overweight vehicle operations. While this quantity is critical in calculating pavement impacts from overweight vehicles, it does not offer any information on the relative severity of the overweight problem at a particular location. That is, for example, a large value of excess ESAL-miles of travel at a given STARS site could reflect an underlying large volume of traffic with a low incidence of overweight vehicles, or it could reflect a small amount of traffic with a high incidence of overweight vehicles. This distinction could be important in arriving at enforcement allocation decisions. Therefore, it was suggested that an additional parameter be calculated that indicates the relative severity of overweight vehicle impacts independent of the absolute volume of traffic.

The pavement damage parameter suggested for use is the excess ESALs associated with overweight vehicle operations divided by the total ESALs of pavement demand at a particular location. Note that this parameter will complement, rather than replace, the existing measure of pavement demand used by MEARS of excess ESAL-miles of travel. Most of the information required to calculate the new parameter is already available in MEARS. The only new variable is the total ESALs of pavement demand at a given location, which can be simply estimated as the total number of vehicles of each configuration multiplied by the average ESAL factor for that configuration (which is already calculated by MDT for pavement design purposes). Typical values of this parameter calculated using historical data available from the initial STARS evaluation ranged from 1.2 to 63.8 percent, for the year prior to these sites being the subject of STARS focused enforcement. During the following year of STARS focused enforcement, the excess ESALs from overweight vehicles at these sites dropped to 0.4 to 18.2 percent of the total ESALS of demand that they experienced. The decrease in the relative severity of the overweight vehicle impacts at these sites as a result of enforcement is apparent. The exact significance of the absolute values of this new damage parameter, as well as the significance of the quantitative changes in its value with enforcement, should become more clear over time as additional experience is gained with its calculation.

In using STARS information to assess the infrastructure damage associated with overweight vehicle operation, it is necessary to know not only the number of overweight vehicles that pass over a site and the amount by which they are overweight, but also the distance they travel. The former information is calculated directly by MEARS from the WIM data. The latter information on distance traveled is more difficult to determine. In calculating infrastructure impacts in the initial STARS evaluation, the traffic observed at a STARS site was assumed simply to traverse the segment of roadway containing the STARS site itself, as defined by the first junction with a highway, Interstate or state line upstream and downstream of the site. Naturally, many of the vehicles that pass a STARS site continue to travel on beyond the end of the road segment containing the STARS site. In the absence of origin-destination data for the vehicles traveling through each STARS site, their travel before and after they crossed a given STARS site was deduced based on 1) general knowledge of the transportation corridors and type of economic activity that occurs between the population centers in the state, and 2) commercial vehicle counts available along the highways in the state. The generally sparse population of the state, and often the availability of only a single major roadway connecting the population centers within the state, significantly reduced the uncertainty of these analyses. Nonetheless, in light of the somewhat subjective nature of the methodology that was used, the results of these analyses need to be closely scrutinized by MDT and revised as necessary. The outcome of these analyses was an "equivalent" length of the highway system associated with each STARS site that was calculated by summing the product of the length of a segment of roadway times the percent of vehicles that it carried that also passed the STARS site.

With the determination of the factors described above to adjust the output from MEARS to account for the presence of compliant but over standard weight vehicles in the traffic stream, it is possible to "exactly" determine that fraction of the over standard weight vehicles at a STARS site that are operating illegally, and to then further determine the maximum benefit (that is, the cost savings in reduced pavement damage) that can be realized by totally eliminating their operation through enforcement. This information obviously is of interest in formulating enforcement resource allocation decisions. In some instances, for example, the maximum benefit to be realized may be either so small or so large that the decision whether or not to commit more enforcement resources to a site may be readily apparent. In other cases, the decision may be less clear, and use of more sophisticated decision making tools may be necessary. The final task completed in this study was to investigate the nature of such a tool and to determine the work required for its development.

Enforcement resource allocation would be well supported by development of an *Enforcement Planning System* (EPS). The EPS would interface with existing MDT systems to support the user in making enforcement assignments to maximize effectiveness. Correlation of historical enforcement effort with reduction in pavement damage costs would form the basis of computer models that would be used for evaluating enforcement plans. These models would then use WIM and other data from MEARS to predict outcomes for assigning officers in a "what-if" mode. Coupled with search algorithms, the models could also be used to generate assignment recommendations in a "what's-best," or optimization, mode. Users would interact with the EPS through an intuitive, map-based, graphical interface. Finally, the EPS would be developed to be easily adapted by other states.

A prototype (http://www.ime.montana.edu/~mdt/eps) was developed to demonstrate elements of the EPS. Interaction is provided by a map-based user interface and dynamic data is stored in a relational database. As currently implemented, displays can be selected to show map features and charts of the WIM data for selected sites. Also included is the ability to view WIM traffic distribution effects. The interface utilizes scalable vector graphics technology (SVG) and will be enhanced considerably during the EPS development. Full development of the EPS is estimated to take two years and will cost approximately $370,000.

1 INTRODUCTION

1.1 Project Background

Since its deployment and activation approximately 5 years ago, Montana's State Truck Activities Reporting System (STARS) has been providing valuable information to the Montana Department of Transportation (MDT) on commercial vehicle activity on the state's highways. Using this system, data on vehicle weight and configuration is continuously being collected at 28 sites around the state using sensors embedded in the roadway. This data subsequently is processed (using software developed for MDT) to obtain the data necessary to support a variety of MDT's functions, from vehicle weight enforcement, to roadway design, to transportation planning. Relative to weight enforcement, it is intuitively obvious that the data collected by STARS should be useful in the state's weight enforcement efforts. Indeed, coincident with the deployment and initial gathering of data using the STARS hardware, the Measurement of Enforcement Activities Reporting System (MEARS) was developed under the direction of the Motor Carrier Services (MCS) and Planning Divisions of MDT, with the intent that MEARS provide MCS with information to help improve the efficiency and effectiveness of Montana's weight enforcement activities. MEARS reports the amount of overweight vehicle activity at each STARS site by vehicle configuration, time-of-day, day-of-week, and direction of travel. Use of STARS in weight enforcement was subsequently experimented with in a pilot project conducted after STARS was operational. In this project, information from MEARS was used to help direct MCS weight enforcement personnel to those locations known from STARS to be experiencing the most severe overweight vehicle problems. The pilot project was successful, in that overweight vehicle activity, as characterized by MEARS, decreased during the STARS focused enforcement effort (Stephens, Carson, Reagor, and Harrington, 2003).

As might be expected, in the absence of any previous experience with a tool of this type (either within Montana or by other transportation agencies around the country), some issues were identified in the pilot project that merited further investigation relative to using this new tool in weight enforcement. These issues were further explored in a follow-on study on the use of STARS in MDT's activities (Stephens and Carson, 2005). The objectives of the follow-on study included calculating the benefit-to-cost ratio for STARS during the pilot program, further validating that the STARS focused enforcement effort was responsible for the reduction in overweight vehicle operations during the pilot project, investigating strategies for the continued use of STARS in enforcing vehicle weight limits, experimenting with methodologies for identifying permitted over standard weight vehicles in the traffic stream, studying bypass behavior during STARS focused enforcement efforts, determining the extent of the highway system impacted by operations at a specific STARS site, and reviewing possible improvements in the manner in which data is processed by MEARS.

At the end of the follow-on study, some issues still remained unresolved (either because they simply could not be addressed within the budget and time constraints of the follow-on study, or they were identified during the follow-on study, itself). These issues included further developing factors to adjust the information from STARS to account for the presence of permitted over standard weight vehicles in the traffic stream, normalizing the pavement damage attributed to overweight vehicle travel to eliminate traffic volume effects from this parameter, refining the estimate of the extent of the infrastructure impacts produced by enforcement activities at each specific STARS, and better identifying the future role of STARS in improving and evaluating the effectiveness of the state's vehicle weight enforcement activities.

Ultimately, MCS would like to include STARS/MEARS related elements in the plan it submits to the Federal Highway Administration at the beginning of each year describing its proposed commercial vehicle size and weight enforcement activities and the manner in which the effectiveness of these activities will be evaluated. The objective of FHWA's plan and certification process is to insure that adequate measures are being taken by the state to control oversize and overweight vehicles "to prevent premature deterioration of the highway pavement and structures and to provide a safe driving environment" (U.S. Government, 2004). Thus, information available from MEARS regarding the level of overweight vehicle operations on the state's highways and the infrastructure damage attributable to these vehicles should be useful in this plan and certification process. The specific manner in which STARS could be used in this regard, however, is unknown.

1.2 Objectives and Scope

The objective of this addendum to the STARS evaluation was to continue the development of STARS (and MEARS) as a tool for MCS to use in its weight enforcement activities. Based on the work accomplished to-date, and discussions with MCS and Planning personnel at MDT, the following tasks specifically were proposed for this addendum:

(1) determine a set of factors to adjust the information from STARS, as processed by MEARS, to account for the presence of permitted over standard weight vehicles in the traffic stream.
(2) develop a new metric to quantify the infrastructure damage attributed to overweight vehicles. Historically, MEARS calculated the absolute pavement damage attributable to overweight vehicles relative to some reference period. Depending on the outcome of this investigation, a new parameter, normalized to some measure of total infrastructure damage incurred at a site, will be developed.
(3) review the extent of the highway system impacted by enforcement activities at a given STARS site.
(4) explore the manner in which level of effort (cost) can be factored into STARS based enforcement decisions.
(5) make suggestions on the possible inclusion of a STARS related component in the state submittal to FHWA for the weight enforcement plan and certification process.

Significant progress was made in this investigation on the first four tasks enumerated above. These efforts are described in detail in the succeeding sections of this report, after a brief introduction to the overall STARS program. Work on tasks one and three focused on the 16 STARS sites studied in the original STARS evaluation, with the intent of validating the basic analysis methodologies and demonstrating the usefulness of their results, before applying them at all 28 active STARS sites. Due to time and resource constraints, little work was accomplished on the fifth task, above, that is, the formulation of specific suggestions on how STARS can factor into the federal weight enforcement plan and certification process. The exact manner in which STARS factors into this process may be influenced by future modifications in the MEARS analysis algorithms, based on the work done in this investigation.

2 DESCRIPTION OF STARS

2.1 General Remarks

Before addressing the specific tasks of this evaluation, a general description of the STARS program is presented below. Information is provided on the STARS hardware and software, and on the performance evaluations conducted for the program to-date.

2.2 STARS Hardware

STARS consists of a network of permanent WIM sites (28 of which had been installed at the beginning of this evaluation out of a total of 35 planned sites) supplemented by 62 sites that are operated intermittently on a three-year cycle using fully portable WIM equipment. Included in these sites are four automated weigh stations that utilize WIM and Automatic Vehicle Identification (AVI) equipment to allow legal bypass of weigh station facilities by credentialed weight-compliant commercial vehicles. Data collected from these automated weigh stations is treated just like the data collected at the STARS WIM sites.

The completed permanent WIM sites, shown in Figure 1 and described in Table 1, are placed around the state on major routes that carry significant truck traffic. Locations were generally selected based on the volume of commercial vehicle traffic carried on the various routes and systems (i.e., secondary, primary, non-Interstate NHS, Interstate) and the location of existing weigh station facilities, with due consideration of the recommendations of FHWA's *Traffic Monitoring Guide* (FHWA, 2001). Since weigh station coverage is greatest on the Interstate system, the STARS sites are focused on the non-Interstate NHS and primary routes around the state. The portable sites additionally cover less-traveled routes known to continuously or seasonally experience significant truck traffic. The precise location of each WIM installation along a particular route was determined based on siting requirements of the WIM system, itself (e.g., roadway grade and alignment criteria, etc.). In light of STARS potential role in weight enforcement, consideration was also given in the siting process to the location of places in the vicinity of each site at which vehicles could be safely pulled off the highway during an enforcement activity.

The specific hardware installed at each of the 28 permanent sites is listed in Table 1. Of the three types of WIM sensors commonly used - piezoelectric, bending plate and permanent load cell - the majority of the installations are piezoelectric (25 out of 28); the remainder are bending plate (3 out of 28). The piezoelectric systems were manufactured by Electronic Control Measurement (ECM), while the bending plate systems were manufactured by PAT America. The relative accuracy and cost of these WIM systems continues to be a subject of debate among the public agencies that use them. The piezoelectric sensors are expected to provide adequate accuracy for MDT's intended use at the most attractive life cycle cost, based on MDT's experience to-date with these technologies and preliminary results from active research projects investigating their performance (Clark, Carson, and Stephens, 2004).

MDT calibrates the permanent WIM sites twice each year according to standard procedures using a 5-axle tractor, semi-trailer of known weight. MDT also performs standard quality control checks on the raw and processed data.

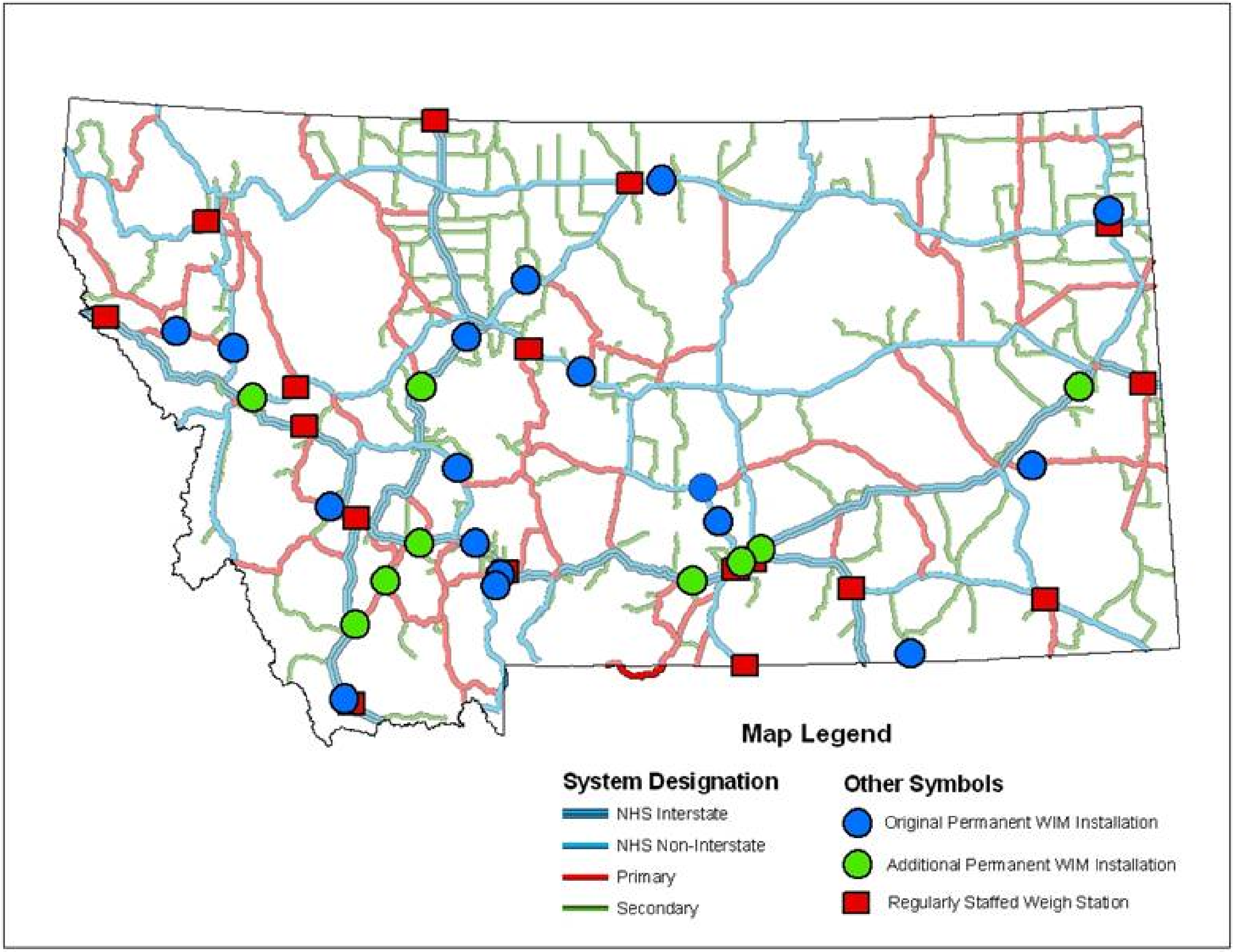


Figure 1. Montana's On-System Highways, Weigh Stations and STARS Sites (Little, 2005)

Table 1. Installed WIM Systems, Location and Equipment (Bisom, 2005; Duke, 2005)

Site[a]	Highway System	Route	Technology
Townsend	Non-Interstate NHS	N-8	Piezoelectric
Decker	Secondary	S-314	Piezoelectric
Bad Route	Interstate	I-94	Piezoelectric
Manhattan	Interstate	I-90	Piezoelectric
Arlee	Non-Interstate NHS	N-5	Piezoelectric
Four Corners[b]	Non-Interstate NHS	N-50	Piezoelectric
Gallatin[b]	Non-Interstate NHS	N-50	Piezoelectric
Galen	Secondary	S-273	Piezoelectric
Broadview	Non-Interstate NHS	N-53	Piezoelectric
Miles City East	Primary	P-2	Piezoelectric
Ulm	Interstate	I-15	Piezoelectric
Ryegate	Non-Interstate NHS	N-14	Piezoelectric
Stanford	Non-Interstate NHS	N-57	Piezoelectric
Fort Benton	Non-Interstate NHS	N-10	Piezoelectric
Havre East	Non-Interstate NHS	N-1	Piezoelectric
Twin Bridges	Primary	P-49	Piezoelectric
Paradise	Primary	P-35	Piezoelectric
Mossmain[c]	Interstate	I-90 West I-90 East	Piezoelectric/ Bending Plate Bending plate
Culbertson[c]	Non-Interstate NHS	N-62	Bending plate
Lima[c]	Interstate	I-15	Bending plate
Armington[c]	Non-Interstate NHS	N-57 East N-57 West	Piezoelectric Piezoelectric
Columbus	Interstate	I-90	Piezoelectric
Turah	Interstate	I-90	Piezoelectric
Dillon	Interstate	I-15	Piezoelectric
Pine Hills	Interstate	I-90	Piezoelectric
Wolf Creek	Interstate	I-15	Piezoelectric
Cardwell	Interstate	I-90	Piezoelectric
Boulder South	Primary	P-69	Piezoelectric

[a] Bold type: site included in initial STARS evaluation

[b] Data considered collectively from both sites, in light of their close juxtaposition

[c] PrePass Site (one direction only, unless indicated otherwise)

2.3 Software Components

The data collected at the various WIM sites is automatically analyzed using the Measurement of Enforcement Activities Reporting System (MEARS) computer software program specifically developed for MDT. MEARS generates reports on the commercial vehicle activity by site and month and for the entire year. Reports are also generated on the general performance of the WIM hardware. The full suite of reports available from MEARS is summarized in Table 2.

2.4 Initial STARS Evaluation

An initial evaluation of STARS was completed by Montana State University in 2003 (Stephens, Carson, Reagor, and Harrington, 2003). This evaluation found that STARS had met three of its primary objectives, namely,

(1) improving the efficiency and effectiveness of truck weight enforcement activities performed by the MCS Division of MDT,
(2) providing MDT access to improved truck-related data for use in pavement design, and
(3) providing various divisions within MDT access to improved truck-related data for use in engineering and planning applications.

Between 2000 and 2002, the MCS Division of MDT conducted a pilot project to investigate the use of STARS data in scheduling mobile weight enforcement activities. Data from STARS was used to identify those locations around the state that historically experienced the worst pavement damage from overweight vehicles. Instrumental in identifying these locations, which were then the object of focused enforcement, was the MEARS software. As a result of this activity, a statistically significant reduction was seen in the percent of overweight vehicles in the traffic stream. Statewide, throughout the extensive network of highways covered by STARS, the percent of overweight vehicles in the traffic stream dropped by 22 percent (from being 8.8 percent of the commercial vehicles in the traffic stream in the baseline year to 6.9 percent in the enforcement year). The average amount of overweight on each vehicle also decreased by 16 percent in the enforcement year. The overall reduction in pavement damage attributable to the focused enforcement effort over the year was on the order of magnitude of 6 million ESAL-miles of travel[1]. The cost savings associated with this change in pavement damage was estimated to be approximately $700,000.

In the area of pavement design, STARS was found to offer better information on the traffic related fatigue demands used in design, relative to the existing information that is collected for this purpose at permanent weigh stations. From a geographic perspective, STARS collects information at more locations around the state than is available at the existing weigh stations. From a temporal perspective, STARS collects data continuously at these sites, while weight data for pavement design purposes is only collected at the weigh stations at a few selected times during the year. Using STARS data in the pavement design process (rather than weigh station

[1] An ESAL (equivalent single axle load) is a unit of measure originally developed by AASHTO to quantify the fatigue demands placed on a highway over its design life by a diverse traffic stream. The ESALs of fatigue demand associated with any given vehicle can be calculated from its axle configuration and axle weights. The total fatigue demand over a segment of highway can be calculated as the product of the ESALs it experiences times its length (often expressed as ESAL-miles).

Table 2. MEARS Reports (Bisom, 2003) by Month and By Site (unless otherwise indicated)

25: Overweight Vehicle Report by Class Number of commercial vehicles Percent of overweight commercial vehicles Average amount of legal weight exceedance **30: Overweight Violations by Time Period and Class** Day of week and 4-hour segment of day Direction of travel **35: Weight Information by Class** Number of commercial vehicles Percent of overweight commercial vehicles Average operating weight Average amount of legal weight exceedance **40: Scatter Graphs by Class** Scatter graph of overweight commercial vehicle events as a function of day of week and time of day **45: Calibration Tracking** Weight frequency plots of vehicles in the traffic stream used for auto-calibration	**70: Summary of Records Violating Rules** Total number of records that violate rules validating reasonableness of recorded vehicle characteristics **90: Truck Weight Upload Process Summary Report** Total number of records screened Total number of bad records **105: Site Activities Roll-up** Total number of vehicles Total number of commercial vehicles Percent of overweight commercial vehicles Average amount of legal weight exceedance Change in overweight commercial vehicle percent Change in average legal weight exceedance amount **205: ESAL Report** Excess ESALs attributable to overweight vehicles by duration of reporting period

data) was projected to annually save approximately $0.7 million and $3.5 million per year on the Interstate and non-Interstate NHS/Primary systems, respectively, through the generation of more cost effective pavement designs.

The final issue considered in this evaluation was the possible benefits STARS offers to traffic data users throughout MDT. A survey across the major divisions at MDT found that STARS data will primarily benefit planning, engineering, and commercial vehicle enforcement efforts.

2.5 STARS Addendum Evaluation 2003-2004

Several issues regarding the present and future use of STARS in MDT's activities that were identified in the initial evaluation were further investigated in a follow-on evaluation/development effort conducted in 2003 – 2004. From its inception, it was expected that *STARS* would only continue to be supported beyond its initial evaluation if the value of the benefit that it offered exceeded its cost. In this follow-on evaluation, the benefit-to-cost ratio of the STARS program was conservatively found to be from 6.3 to 10.6, using an assumed service life for the WIM equipment of 4 to 12 years, respectively. While encouraging results were obtained in the initial evaluation relative to the benefits of STARS focused enforcement, this evaluation was conducted over a relatively short period of time, during which commercial vehicle operations could have been affected by a variety of factors. Subsequent analysis of the data collected since the completion of the original evaluation further supported the conclusion that the STARS focused enforcement effort was responsible for the reduction in pavement demand (and the attendant savings in pavement damage costs) observed in the original evaluation period.

The future role of STARS related information in both planning and evaluating the effectiveness of the state's weight enforcement efforts was explored. In this regard, the manner in which the temporal and geographic variability of commercial vehicle operations can impact STARS based scheduling decisions, as well as the outcome of STARS based evaluations of enforcement effectiveness, were generally described. Certainly, the fundamental value of STARS in helping with either of these activities is dependent on the quality of the information on overweight vehicle operations that it provides. In this regard, some issues were known to exist relative to the presence of permitted over standard weight vehicles in the traffic stream. A methodology was proposed and demonstrated for identifying such vehicles directly from the STARS WIM data. Finally, the pavement damage estimates provided by MEARS are crucial to its usefulness, and the accuracy of the approximate method used in MEARS make these estimates was confirmed.

3 COMPLIANT BUT OVER "STANDARD" WEIGHT VEHICLES

3.1 General Remarks

Presently, any vehicle whose weight exceeds standard gross weight limits by any amount, and for any reason, is simply identified by MEARS as overweight. While this approach to identifying overweight vehicles is easy to analytically execute, it may also result in the number of vehicles that are operating illegally above "standard" gross weight limits to be overstated. Obviously, this situation is problematic relative to using MEARS to characterize overweight vehicle operations for weight enforcement related purposes. The objective of this part of this study was to determine adjustment factors to be applied in MEARS to account for the presence of over standard weight vehicles in the traffic stream that are compliant with applicable weight limits. These adjustment factors were determined for selected STARS sites around the state, and average adjustment factors by highways system (secondary, primary, non-Interstate NHS, and Interstate) were calculated. The adjustment factors were subsequently applied to selected MEARS analyses, to qualitatively assess their effect on the results of such analyses and to determine what advantages they may offer in using STARS in weight enforcement related endeavors.

3.2 Description of the Problem

The potential sources of bias that could lead to the overstatement of the number of overweight vehicles in the traffic stream by MEARS are threefold, as described below.

3.2.1 Variable Maximum Gross Weight Limit

MEARS identifies overweight vehicles based on fixed gross weight limits that have been established for each class of vehicles (e.g., 46,000 pounds on a Type 6-1, 3 axle straight truck). In Montana, however, the maximum gross weight that a vehicle can legally carry is more directly dependent on the specific spacings between the axles within the vehicle than it is on the general vehicle class to which it belongs. That is, the Federal Bridge Formula is one criterion used to determine the maximum gross weight that a vehicle can carry. Following this formula, the maximum gross weight is dependent on both the number of axles in the collection of axles being considered, as well as their spacing. Thus, any given vehicle in a particular class could have a different maximum allowable gross weight, if it has different axle spacings. The maximum gross vehicle weights by vehicle configuration used in MEARS were developed for a "typical" axle geometry and loading pattern observed for each class (with due consideration of maximum loads that axles can practically and legally carry). Use of special equipment or atypical axle spacings can result in a vehicle of a given configuration being able to legally weigh more than the standard weight limit assigned in MEARS.

In the case of the Class 6-1, 3 axle truck mentioned above, for example, the maximum gross weight of 46,000 pounds is assumed to be carried as 12,000 pounds on the single steer axle (which is considerably below the single axle weight limit of 20,000 pounds) and 34,000 pounds on the back tandem axles (at the weight limit for a tandem axle group). If the gross weight of a vehicle of this class exceeds 46,000 pounds, the extra weight is assumed in MEARS to be carried by the tandem axle group, which results in the vehicle violating the maximum allowable axle weight on a tandem, and the vehicle is identified as overweight. In reality, this vehicle could be configured so that the total weight is distributed to the steer axle and tandem in such a manner that it complies with both the individual axle weight limits in Montana and the Federal Bridge Formula.

Early in the STARS program, a limited study was done on the relative accuracy of identifying overweight vehicles based simply on exceedance of "standard" gross weight limits compared to a more thorough consideration of gross weight, individual axle group weight, and combined axle group weight. In this study, less than a 10 percent difference was seen in the number of overweight vehicles identified by each approach. Therefore, the decision was made to simply identify overweight vehicles based on gross vehicle weight. However, it is possible that a high percentage of "atypical" vehicles of a given class might be operating at certain STARS sites in response to a specific regional transportation need, and at such locations, the overweight vehicle information from MEARS should be adjusted to correct for the presence of these vehicles in the traffic stream.

3.2.2 Absolute Maximum Gross Weight Limit

MEARS presently uses the exact statutory weight limit to identify overweight vehicles from the WIM data. That is, a vehicle with a recorded WIM weight even one pound over statutory limits is identified as overweight, even if this nominal overweight would not normally result in a citation being issued. At certain STARS sites, a substantial number of vehicles identified by MEARS as overweight could fall into this category, and once again, the overweight vehicle information from MEARS should be adjusted to reflect this situation.

3.2.3 Over "Standard" Weight Limit Permits

A final category of vehicles that MEARS identifies as over standard weight that are compliant with statutory weight limits are weight permitted vehicles. Montana allows standard axle and GVW weight limits to be exceeded within certain parameters, generally, if a non-divisible load has to be transported on the state's highways. In light of the significant natural resources based component of the state's economy, a significant number of these vehicles, carrying mining equipment, farm implements, etc, operate on certain segments of the state's highways. It is difficult to identify the vehicles that are permitted to legally operate in excess of standard weight limits just based on the data collected by STARS. Nonetheless, the overweight vehicle population as identified by MEARS should be adjusted to account for the presence of over standard weight permitted vehicles in the traffic stream.

3.3 Solution Methodology

The methodology proposed herein for adjusting the WIM data collected by STARS to account for compliant over standard weight vehicles in the traffic stream was first introduced in the work done for the initial addendum to the STARS evaluation project (Stephens and Carson, 2005). The methodology is founded upon two assumptions:

(1) on average across some period of time, permitted vehicle traffic at any given *STARS* site is constant and repeatable in nature, and
(2) during visible and obvious weight enforcement activities, those vehicles whose axle weights and/or gross vehicle weight exceed standard limits fall into one of the three situations described above, and they can be considered compliant with all applicable weight limits.

The first of these assumptions allows for an adjustment factor to be developed from a sample of the vehicle traffic at a site that can subsequently be applied continuously across the traffic at that site. The second assumption provides a mechanism for developing such an adjustment factor. The reasonableness of the first assumption depends on how uniform and recurring the pattern of compliant but over standard weight vehicle traffic is at a given site. While definitive information of this kind presently is unavailable, the weight enforcement community may have sufficient knowledge of general vehicle operations at each site for the adjustment factor approach to still reasonably be applied. Obviously, if the pattern of permitted vehicle traffic is uniform and recurring, an adjustment factor developed from a discrete sample of this traffic can be used with good results across any subsequent time interval. A site with a high volume of traffic carrying diverse goods will be less sensitive to seasonal vehicle movements, and thus possibly will have relatively uniform and recurring permitted vehicle traffic.

Conversely, as the timing and/or volume of traffic on a route becomes more variable, obtaining a representative sample of this traffic from which to characterize compliant but over standard weight vehicle activity is more difficult. Furthermore, the applicability of a single adjustment factor calculated for a short period of time across all subsequent times, during which the character of the traffic can change substantially, is questionable. In this case, it may be desirable to develop and apply different adjustment factors for different time periods or events (e.g., harvest versus other times of year on a farm to market route). Note that a single adjustment factor can still be applied to such sites across any given time period (say, annually), using a weighted average of the individual adjustment factors for each subinterval.

The second assumption introduced above, namely, that the overwhelming majority of vehicles that operate during visible and obvious weight enforcement activities are in compliance with all applicable weight limits, allows for the relatively simple identification of the amount of over standard weight, but weight compliant vehicles in the traffic stream (i.e., vehicles with atypical dimensions and axle loading patterns, vehicles with weights that are only nominally in excess of established limits, and weight permitted vehicles, as outlined above). The basic and probably obvious rational behind this assumption is that over standard weight vehicles that are operating illegally will not generally enter the traffic stream if they know that they will be weighed and cited. The qualifier "generally" is used in this instance because it has been observed that even when weigh stations are open, one or two percent of commercial vehicles will be overweight. Thus, even in the presence of obvious enforcement, some of the over standard weight vehicles in the traffic stream could be operating illegally.

If the second assumption above is valid, than WIM records collected during a period of overt enforcement can be used to determine adjustment factors to account for the compliant over standard weight vehicles in the traffic stream. That is, any record in which axle weights or gross vehicles weights exceed standard limits corresponds to such a vehicle (ignoring the one to two percent of vehicles that operate illegally during overt enforcement activities). Note that the objective of the “overt” enforcement activity referred to above is simply to produce a traffic stream containing only weight compliant vehicles. Thus, this activity can consist of any tasks that will insure this condition. Notably, not every truck has to be weighed or even stopped during this activity.

3.4 Implementation

The above described methodology was used to determine adjustment factors for those WIM sites at which enforcement was engaged in during the year of focused enforcement in the first STARS evaluation effort. In that effort, part of MDT's weight enforcement effort each month was directed to five critical sites, as determined by historical information on overweight vehicle operations provided by MEARS from data collected at STARS sites around the state. At the time of that study (which began in May, 2000), a total of 16 STARS sites were in operation (see Table 1). While the STARS system had grown to number 28 active sites at the beginning of this investigation, this study focused on the 16 sites considered in the initial evaluation, and more specifically, on the sites at which enforcement activities were engaged in during the year of focused enforcement. The enforcement activities that were engaged in at these sites during the initial evaluation were part of a large-scale coordinated effort, and thus they offered a degree of uniformity in their execution and documentation that made them especially attractive for this analysis.

Focused enforcement activities were engaged in at nine different STARS sites during the second year of the initial STARS evaluation (see Table 3). Two of the sites were on the Interstate system; five on the non-Interstate NHS system; one on the primary system; and one on the secondary system. The relative distribution of these STARS sites (by system of the highway network) is similar to that seen in the overall population of STARS sites across the state. In reviewing the results of this analysis, however, it is important to recognize that these sites were specifically selected for enforcement because of the relatively high level of overweight vehicle activity that they historically experienced. Thus, the compliant but over standard weight vehicle populations at these sites may not be fully representative of these vehicle populations across all STARS sites. The focused enforcement activities that were engaged in at these nine sites are summarized in Table 3. Each month during that year, the five sites that experienced the greatest pavement damage from overweight vehicles during the same month the previous year (referred to as the baseline year), were selected for focused enforcement. During each month of focused enforcement, patrol officer(s) worked each of the five selected sites approximately three days per week, 8 hours per day, following specific suggestions of which days of the week, time of day, vehicle configurations, and direction of travel that they should focus their efforts on. For the purposes of this investigation, it was assumed that even though the officers were provided specific suggestions in this regard, vehicle operators, in general, were not aware of these suggestions, and that "all" illegal overweight vehicle activity would be curtailed when the officers were present.

MEARS was run on a sample of the specific days during which these enforcement activities were conducted (for the specific times over which they were conducted each day), and the over standard weight vehicles identified by MEARS during these times were presumed to be those vehicles that exceeded standard weight limits but were compliant with all applicable weight requirements. Selection of the specific days that were used in this analysis (see Table 3) was an uncertain task. The volume and composition of the traffic at any given site and at any given time is influenced by a myriad of factors, from the condition of the economy to the condition of the weather. The decision was made in these analyses to consider five enforcement days arbitrarily chosen from the approximately 12 enforcement days in each month. The decision was then further made to sample, as possible, one month from each major season of the year, whenever

Table 3. STARS Directed Enforcement Activities, Initial STARS Evaluation

Site	System[a]	Enforcement Activity[b] 2001								Enforcement Activity[b] 2002				No. of Months	
		May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Enf.	Sampled
Decker	S					4,11,17, 25,26	X				4,7,8, 13,15			3	2
Miles City East	P				3,9,10, 16,24					-	-			1	1
Ryegate	N					X		5,6,8, 13,19		4,7,9, 11,18	X	12,14,15, 26,28	X	7	3
Stanford	N	X	6,7,12, 13,14	X	X	13,17,19, 20,27	X	5,7,8, 14,19			7,12,14, 15,19	X	X	10	4
Four Corners Gallatin	N	X	XX	18,19,23, 25,26	X	11,12,13, 18,19	X	X	4,5,10, 12,14	X	X	12,14,19, 26,28	X	14	4
Townsend	N	X	4,5,7,12, 14	X	X	12,14,17, 20	X	X	5,11,12, 13,19			X	X	10	3
Arlee	N			6,12,13, 18,20						7,10,15, 17,23				2	2
Manhattan	I						3,4,17, 22,24			7,9,10, 14,16	-	-		2	2
Ulm	I							6,7,13, 15,20		X	8,12,22	-	-	4	2
All		-	-	-	-	-	-	-		-	-	-	-	53	23

[a] S – Secondary; P – Primary; N – Non-Interstate NHS; I – Interstate

[b] X – Subject of focused enforcement for indicated month; Numerical Values – Specific months and days used in this analysis

possible. Note that in this regard, only three of the eight sites were enforced during all four seasons of the year. In all cases, adjustment factors were then calculated for each day, and these results were then aggregated using a weighted average based on volume of traffic to obtain correction factors for the month, which were further aggregated to obtain correction factors for a year. All calculations were performed by vehicle class and site.

The adjustment factors were calculated in terms of the percent of vehicles in the traffic stream that were compliant but over standard weight, and the excess ESALs associated with their operation. These factors can be simply applied to the results of the current MEARS algorithms in the following fashion to more accurately identify those vehicles in the traffic stream that are both over standard weight and that are operating illegally:

(1) The total number of commercial vehicles at a site can be multiplied by the percent of those vehicles that are over standard weight, but weight compliant. This number of vehicles can then be subtracted from the total number of over standard weight vehicles at the site (with the difference taken as greater than or equal to zero) before further overweight vehicle calculations are done.
(2) The total number of commercial vehicles at a site can be multiplied by the average excess ESALs per vehicle attributable to over standard weight but weight compliant vehicles. These excess ESALs are subtracted from the total excess ESALs (with the difference taken as greater than or equal to zero) before further pavement damage calculations are done.

In applying the adjustment factors in this simple manner, some additional assumptions inherently are being made relative to the presence of over standard weight but compliant vehicles in the traffic stream. Notably, the enforcement activities used in this analysis were scheduled on specific days of the week (which in this case were restricted to week days) and during specific times of the day (typically, eight hour blocks corresponding to known times of heavy vehicle operations). Based on the manner in which the adjustment factors are being used, these specific periods were assumed to be representative of the pattern of heavy over standard weight vehicle operation throughout the day and week. The validity of this assumption can easily be checked, or the calculation of the adjustment factors can easily be refined, by scheduling enforcement activities over all periods of the day. Relative to these analyses, the fact that time constrained data was used should be considered as the reader interprets the results.

3.5 Results

3.5.1 General Remarks

Summaries of the adjustment factors calculated for the percent of overweight vehicles in the traffic stream and the excess equivalent single axle loads (ESALs) of pavement damage associated with their operation are presented in Tables 4 and 5, respectively, by site and system of the state's highway network. Complete results of the adjustment factor analyses on a month-by-month and site-by-site basis are presented in Appendix B. Selected results from these analyses are discussed below.

Prior to conducting this adjustment factor analysis, a limited investigation was done of the variation in the proportion of compliant but over standard weight vehicles in the traffic stream on different days during a single month. The percent of compliant but over standard weight

Table 4. Aggregated Adjustment Factors, Percent of Overweight Vehicles, by Site and Highway System

Vehicle Class[a]	Percent of Compliant but Over Standard Weight Vehicles by Site									Percent of Compliant Over Standard Weight Vehicles by System				
	Decker	Miles City East	Arlee	Four Corners Gallatin	Town-send	Ryegate	Stanford	Manhat-tan	Ulm					
System[b]	S	P	N	N	N	N	N	I	I	S	P	N	I	All
Months Analyzed	2	1	2	4	3	3	4	2	2	2	1	16	4	23
4 – 1	0.0	0.0	0.0	0.0	1.6	0.0	10.2	0.0	0.0	0.0	0.0	1.9	0.0	1.3
4 – 2	25.0	0.0	3.7	3.4	10.3	0.0	7.7	11.4	10.7	25.0	0.0	5.3	11.2	8.1
5 – 1	1.9	0.0	0.2	1.4	0.6	4.3	1.0	0.3	0.0	1.9	0.0	0.9	0.2	0.8
5 – 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 – 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 – 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 – 1	18.8	0.0	0.9	5.7	3.9	3.7	8.2	9.4	12.0	18.8	0.0	3.4	9.9	5.7
7 – 1	20.0	0.0	0.0	21.1	33.3	100.0	0.0	21.4	50.0	20.0	0.0	20.7	25.0	21.8
7 – 2	75.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	75.0	0.0	0.0	0.0	60.0
7 – 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 – 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8 – 2	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.7	2.4	0.0	0.0	0.3	1.1	0.6
9 – 1	22.9	8.8	8.7	13.2	13.2	10.0	12.9	8.2	6.2	22.9	8.8	11.8	7.8	10.0
9 – 2	12.0	0.0	0.0	6.4	2.9	4.7	6.1	2.7	0.9	12.0	0.0	4.3	2.6	3.4
9 – 3	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	0.0	6.3
10 – 1	18.2	12.0	7.5	12.5	7.8	15.5	10.2	11.9	5.7	18.2	12.0	10.9	9.1	10.5
10 – 2	0.0	100.0	9.6	3.6	15.4	26.7	10.5	1.8	7.1	0.0	100.0	12.7	2.9	9.9
10 – 3	0.0	100.0	67.1	50.0	63.6	65.2	43.8	70.0	56.3	0.0	100.0	61.6	66.1	62.9
11 – 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12 – 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13 – 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13 – 2	5.3	0.0	0.0	2.0	3.3	0.6	0.2	1.0	0.5	5.3	0.0	1.0	0.8	1.1
13 – 3	5.6	0.0	22.9	0.0	13.0	4.0	0.0	2.2	0.0	5.6	0.0	15.5	2.0	12.5
13 – 4	11.1	0.0	3.0	2.9	4.7	4.3	2.4	3.0	0.8	11.1	0.0	3.4	2.1	3.4
All	10.3	5.1	5.6	8.0	7.0	9.5	8.1	6.0	4.7	10.3	5.1	7.4	5.7	6.8

[a] See Appendix A for a description of the vehicle classes

[b] S – Secondary; P – Primary; N – Non-Interstate; I – Interstate

Table 5. Aggregated Adjustment Factors, Excess ESALS per Vehicle, by Site and Highway System

Vehicle Class[a]	Compliant Excess ESALs per Vehicle by Site									Compliant Excess ESALS per Vehicle by System				
	Decker	Miles City East	Arlee	Four Corners Gallatin	Town-send	Ryegate	Stanford	Manhat-tan	Ulm					
System[b]	S	P	N	N	N	N	N	I	I	S	P	N	I	All
Months Analyzed	2	1	2	4	3	3	4	2	2	2	1	16	4	23
4 – 1	0.000	0.000	0.000	0.000	0.009	0.000	0.025	0.000	0.000	0.000	0.000	0.006	0.000	0.004
4 – 2	0.113	0.000	0.003	0.002	0.019	0.000	0.013	0.048	0.080	0.113	0.000	0.007	0.057	0.028
5 – 1	0.047	0.000	0.001	0.005	0.004	0.016	0.007	0.001	0.000	0.047	0.000	0.004	0.001	0.007
5 – 2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5 – 3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5 – 4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6 – 1	0.344	0.000	0.008	0.036	0.046	0.027	0.060	0.092	0.196	0.344	0.000	0.028	0.111	0.066
7 – 1	0.014	0.000	0.000	0.046	0.509	0.368	0.000	0.061	0.134	0.014	0.000	0.096	0.070	0.073
7 – 2	0.332	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.332	0.000	0.000	0.000	0.266
7 – 3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8 – 1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8 – 2	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.001	0.001	0.001
9 – 1	0.258	0.017	0.035	0.088	0.104	0.031	0.074	0.033	0.035	0.258	0.017	0.068	0.033	0.053
9 – 2	0.335	0.000	0.000	0.064	0.031	0.058	0.090	0.017	0.014	0.335	0.000	0.052	0.017	0.036
9 – 3	0.000	0.000	0.000	0.920	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.230	0.000	0.115
10 – 1	0.048	0.091	0.042	0.064	0.064	0.059	0.057	0.098	0.011	0.048	0.091	0.058	0.059	0.058
10 – 2	0.000	0.390	0.039	0.006	0.122	0.029	0.003	0.001	0.004	0.000	0.390	0.033	0.002	0.025
10 – 3	0.000	0.038	0.055	0.028	0.059	0.036	0.008	0.047	0.046	0.000	0.038	0.042	0.047	0.043
11 – 1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12 – 1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13 – 1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13 – 2	0.032	0.000	0.000	0.019	0.018	0.003	0.001	0.008	0.001	0.032	0.000	0.007	0.006	0.008
13 – 3	0.028	0.000	0.101	0.000	0.057	0.005	0.000	0.006	0.000	0.028	0.000	0.067	0.005	0.054
13 – 4	0.122	0.000	0.018	0.007	0.020	0.008	0.015	0.014	0.008	0.122	0.000	0.016	0.012	0.019
All	0.134	0.016	0.021	0.064	0.058	0.031	0.054	0.028	0.029	0.134	0.016	0.045	0.028	0.041

[a] See Appendix A for a description of the vehicle classes [b] S – Secondary; P – Primary; N – Non-Interstate NHS; I – Interstate

vehicles in the traffic stream at the Stanford STARS site on 10 different days in November is plotted in Figure 2. The values are all clustered fairly closely around the mean of 7.4 percent (with a standard deviation of 2.2). In this case, the magnitude of the adjustment factors calculated for November would be little affected by arbitrarily selecting any sample of several days upon which to base their calculation. As previously mentioned, a randomly selected sample of 5 days was used in this analysis.

Recognizing the unique nature of the vehicle traffic at each site, this analysis was repeated for the month of June at the Townsend STARS site, with results shown in Figure 3. A possible trend is evident in the volume of over standard weight but compliant vehicles at the Townsend site during this month, with the number of such vehicles in the traffic stream peaking early in the month at around 8 percent and then steadily declining to a value of approximately 2 percent at the end of the month. In this case, the specific days selected in compiling a sample of either 5 or 10 days upon which to base the adjustment factor analysis could have a noticeable impact on the results. Nonetheless, a randomly selected window of 5 days was still used in this analysis, so the results of the analysis could inadvertently reflect the above type of temporal bias.

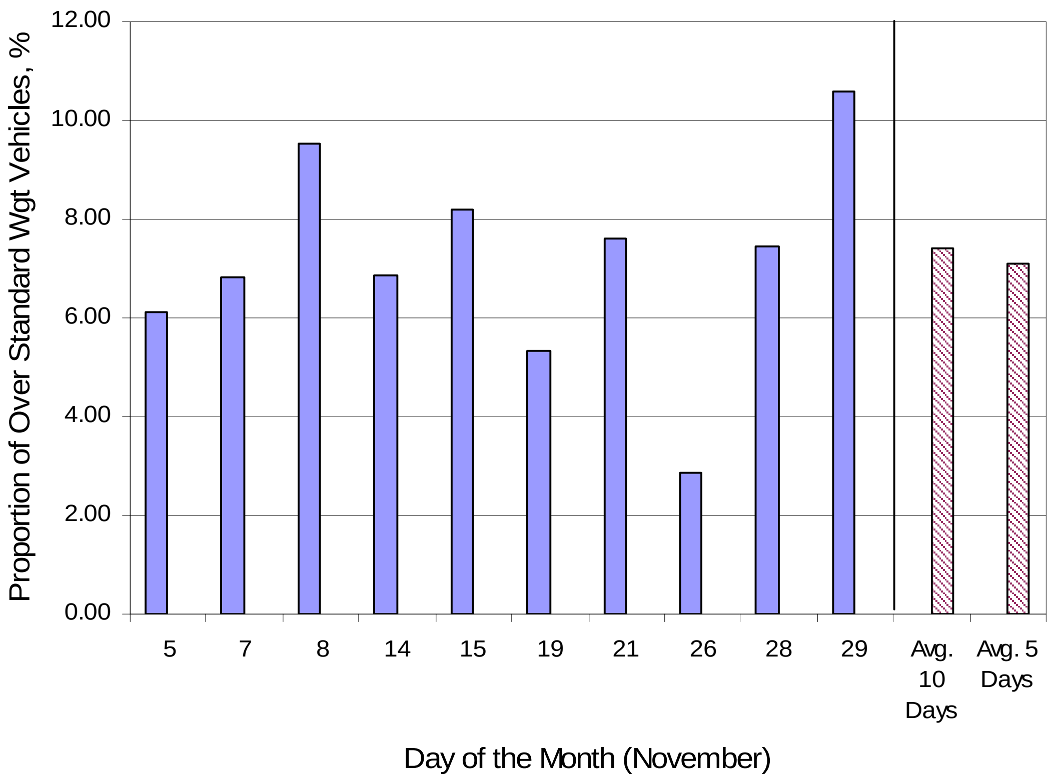


Figure 2. Proportion of Compliant but Over Standard Weight Vehicles, 10 Days in November, Stanford Site

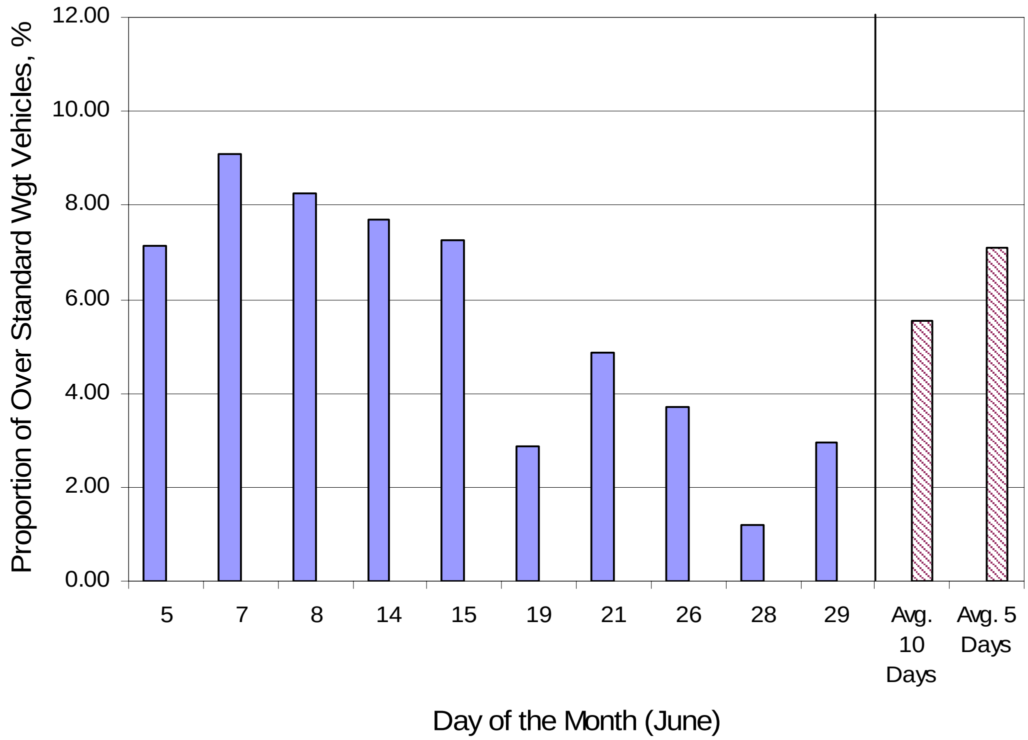


Figure 3. Proportion of Compliant but Over Standard Weight Vehicles, 10 Days in June, Townsend Site

3.5.2 Percent of Overweight Vehicles

Results from the adjustment factor calculations for the percent of overweight vehicles in the traffic stream for four months of the year at a typical site (in this case, the Stanford site) are presented in detail in Table 6. At this site, similarities are evident in the characteristics of the over standard weight but compliant vehicle populations from month-to-month, relative to both the classes that contain such vehicles and the relative proportion of the traffic stream that they represent. The adjustment factors aggregated across the vehicle classes ranged from 7.1 to 9.2 percent. The uniformity of these results suggest that it is reasonable to use a single average adjustment factor at the Stanford site across any time interval (say, for example, from one week to one year in duration).

Once again, traffic differs between sites, and the monthly results from the Four Corners/Gallatin STARS site present a different pattern of over standard weight but compliant vehicle operation relative to that observed at the Stanford site. The adjustment factors calculated for four different months during the year at the Four Corners/Gallatin STARS site are presented in detail in Table 7. In this case, the proportion of over standard weight but compliant vehicles in the traffic stream ranged from 6.0 to 12.9 percent (when aggregated over all vehicle classes). Based on the relatively greater variability of these results over the year, use of a single factor to adjust the data collected at this site over a relatively short time period (i.e., less than a year) would be more problematic than at the Stanford site. Note that at Four Corners/Gallatin site, the types of

Table 6. Monthly Adjustment Factors, Percent of Overweight Vehicles, Stanford Site

Vehicle Class[a]	Percent of Vehicles Over Standard Weight				
	June	September	November	February	Weighted Average
4 – 1	0.0	15.4	20.0	0.0	10.2
4 – 2	0.0	0.0	12.5	12.5	7.7
5 – 1	1.7	1.9	0.0	1.7	1.0
5 – 2	0.0	0.0	0.0	0.0	0.0
5 – 3	0.0	0.0	0.0	0.0	0.0
5 – 4	0.0	0.0	0.0	0.0	0.0
6 – 1	9.8	6.3	6.4	10.0	8.2
7 – 1	0.0	0.0	0.0	0.0	0.0
7 - 2	0.0	0.0	0.0	0.0	0.0
7 - 3	0.0	0.0	0.0	0.0	0.0
8 - 1	0.0	0.0	0.0	0.0	0.0
8 - 2	0.0	0.0	0.0	0.0	0.0
9 - 1	14.6	14.6	10.9	12.2	12.9
9 - 2	4.8	6.2	8.1	4.1	6.1
9 - 3	0.0	0.0	0.0	0.0	0.0
10 - 1	12.3	13.2	5.9	17.2	10.2
10 - 2	0.0	33.3	0.0	50.0	10.5
10 - 3	100.0	0.0	42.3	0.0	43.8
11 - 1	0.0	0.0	0.0	0.0	0.0
12 - 1	0.0	0.0	0.0	0.0	0.0
13 - 1	0.0	0.0	0.0	0.0	0.0
13 - 2	0.0	0.0	0.0	2.0	0.2
13 - 3	0.0	0.0	0.0	0.0	0.0
13 - 4	2.8	0.0	1.8	4.5	2.4
All	8.1	9.2	7.1	8.9	8.10

[a] See Appendix A for a description of the vehicle classes

vehicles that are over standard weight are similar throughout the year; it is the relative proportion of over standard weight vehicles of each class that changes from month-to-month.

The average adjustment factors for percent of overweight vehicles determined at all the enforced sites from the first STARS evaluation effort were previously summarized in Table 4. The highest proportion of compliant over standard weight vehicles across all the sites considered is Class 10-3 vehicles (at 63 percent), followed by Class 7-2 vehicles (at 60 percent). To some extent, these results are controlled by vehicle operations on particular elements of the highway system and the specific data used in this analysis. The compliant over standard weight Class 9-3 vehicles identified in Table 4, for example, were only observed at a single site on the

Table 7. Monthly Adjustment Factors, Percent of Overweight Vehicles, Four Corners/Gallatin Site

Vehicle Class[a]	Percent of Vehicles Over Standard Weight				
	July	September	December	March	Weighted Average
4 - 1	0.0	0.0	0.0	0.0	0.0
4 - 2	3.6	5.9	0.0	0.0	3.4
5 - 1	2.0	0.0	0.0	2.9	1.4
5 - 2	0.0	0.0	0.0	0.0	0.0
5 - 3	0.0	0.0	0.0	0.0	0.0
5 - 4	0.0	0.0	0.0	0.0	0.0
6 - 1	5.4	5.7	10.7	0.0	5.7
7 - 1	20.0	0.0	0.0	100.0	21.1
7 - 2	0.0	0.0	0.0	0.0	0.0
7 - 3	0.0	0.0	0.0	0.0	0.0
8 - 1	0.0	0.0	0.0	0.0	0.0
8 - 2	2.6	0.0	0.0	0.0	1.2
9 - 1	9.3	11.5	15.2	19.0	13.2
9 - 2	3.6	1.2	10.2	12.8	6.4
9 - 3	0.0	100.0	0.0	0.0	50.0
10 - 1	14.6	3.8	17.6	17.6	12.5
10 - 2	0.0	10.0	0.0	0.0	3.6
10 - 3	100.0	25.0	100.0	0.0	50.0
11 - 1	0.0	0.0	0.0	0.0	0.0
12 - 1	0.0	0.0	0.0	0.0	0.0
13 - 1	0.0	0.0	0.0	0.0	0.0
13 - 2	4.0	0.0	2.4	1.3	2.0
13 - 3	0.0	0.0	0.0	0.0	0.0
13 - 4	0.0	25.0	0.0	0.0	2.9
All	6.2	6.0	10.1	12.9	8.02

[a] See Appendix A for a description of the vehicle classes

non-Interstate NHS system. Similarly, the compliant but overweight Class 7-2 vehicles were only seen on the secondary system (and only a single site on that system was used in this analysis).

In an effort to better portray trends in the above results, the information in Table 4 on compliant but over standard weight vehicle operations by configuration and system is plotted in Figure 4. Referring to this figure, compliant but over standard weight Class 7-1, 9-1, and 10-1 vehicles operate fairly consistently on all elements of the highway system (comprising 22, 10, and 11 percent of the vehicles of each configuration, respectively). By system, the lowest proportion of compliant over standard weight vehicles was observed on the primary system (at 5.1 percent),

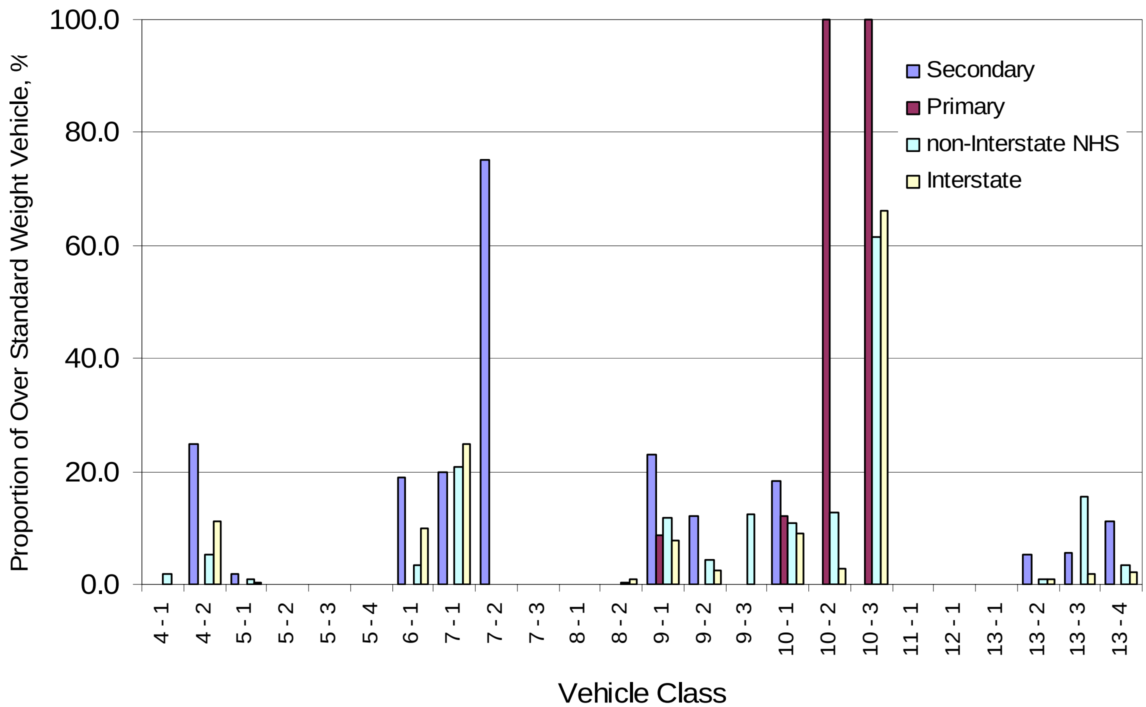


Figure 4. Proportion of Compliant but Over Standard Weight Vehicles by Class and Highway System

although only a single site on the primary system was considered in this analysis (Miles City East), and it was selected for focused enforcement for a single month. Results for the interstate and non-Interstate NHS systems, based on multiple sites and months of enforcement, indicate that 5.7 and 7.4 percent of the vehicles operating on these systems, respectively, are compliant but over standard weight vehicles. The highest proportion of compliant but over standard weight vehicle operations was observed on the secondary system (at 10.3 percent), but once again, only a single secondary site was used in these analyses. Nonetheless, these results appear to be generally consistent with the idea that permitted vehicles and vehicles with unusual axle configurations tend to be engaged in intrastate rather than interstate activity, and thus operate more on intrastate rather than interstate highways.

3.5.3 Excess ESALs from Overweight Vehicles

Factors were also determined in this analysis to adjust the excess ESALs attributable to overweight vehicles (as reported by MEARS) to account for the presence of over standard weight but legally compliant vehicles in the traffic stream. Excess ESAL adjustment factors by configuration (expressed in terms of "compliant" excess ESALs per vehicle) are reported in Table 8 for four months of the year at a typical STARS site (once again, the Stanford site). Referring to Table 8, the relative variation in the excess ESAL adjustment factors across these months is similar in magnitude to the variation in the corresponding adjustment factors for percent of overweight vehicles across these same months. The adjustment factors for the proportion of overweight vehicles each month varied by 30 percent (see Table 6), while the excess ESAL factors varied by as much as 29 percent between months. Again, recognizing the unique nature of the vehicle operations at each site, the excess ESAL adjustment factors

Table 8. Monthly Adjustment Factors, Excess ESALs, Stanford Site

Vehicle Class[a]	Excess ESALs from Compliant but Over Standard Weight Vehicles				
	June	September	November	February	Composite Value
4 – 1	0.000	0.075	0.345	0.000	0.025
4 – 2	0.000	0.000	0.063	0.044	0.013
5 – 1	0.185	0.023	0.000	0.002	0.007
5 – 2	0.000	0.000	0.000	0.000	0.000
5 – 3	0.000	0.000	0.000	0.000	0.000
5 – 4	0.000	0.000	0.000	0.000	0.000
6 – 1	0.023	0.362	0.055	0.061	0.060
7 – 1	0.000	0.000	0.000	0.000	0.000
7 – 2	0.000	0.000	0.000	0.000	0.000
7 – 3	0.000	0.000	0.000	0.000	0.000
8 – 1	0.000	0.000	0.000	0.000	0.000
8 – 2	0.000	0.000	0.000	0.000	0.000
9 – 1	0.077	0.071	0.073	0.075	0.074
9 – 2	0.243	0.083	0.133	0.009	0.090
9 – 3	0.000	0.000	0.000	0.000	0.000
10 – 1	0.083	0.086	0.023	0.080	0.057
10 – 2	0.000	0.018	0.000	0.108	0.003
10 – 3	0.120	0.000	0.016	0.000	0.008
11 - 1	0.000	0.000	0.000	0.000	0.000
12 - 1	0.000	0.000	0.000	0.000	0.000
13 - 1	0.000	0.000	0.000	0.000	0.000
13 - 2	0.000	0.000	0.000	0.007	0.001
13 - 3	0.000	0.000	0.000	0.000	0.000
13 - 4	0.028	0.000	0.030	0.009	0.015
All	0.063	0.058	0.049	0.049	0.054

[a] See Appendix A for a description of the vehicle classes

determined at a second location, Four Corners/Gallatin, are presented in Table 9. At this location, the excess ESAL adjustment factors vary by over a factor of 4 between months.

In light of the apparent degree of their variation through time, care must be exercised in calculating and applying aggregate correction factors to the excess ESALs attributed to overweight vehicles. While an appropriately weighted correction factor, such as the 0.064 excess ESALS per vehicle calculated at the Four Corners/Gallatin site (Table 9), may be reasonably applied across a full year of information from this site, this factor would result in a significant over estimation of the excess ESALs associated with compliant over standard weight vehicles, for example, if it was applied to data collected only in the month of September, which has an aggregate adjustment factor of only 0.028 excess ESALs per vehicle.

Table 9. Monthly Adjustment Factors, Excess ESALs, Four Corners/Gallatin Site

Vehicle Class[a]	Excess ESALs from Compliant but Over Standard Weight Vehicles				
	July	September	December	March	Composite Value
4 - 1	0.000	0.000	0.000	0.000	0.000
4 - 2	0.004	0.036	0.000	0.000	0.002
5 - 1	0.106	0.000	0.000	0.022	0.005
5 - 2	0.000	0.000	0.000	0.000	0.000
5 - 3	0.000	0.000	0.000	0.000	0.000
5 - 4	0.000	0.000	0.000	0.000	0.000
6 - 1	0.030	0.047	0.074	0.000	0.036
7 - 1	0.091	0.000	0.000	0.442	0.046
7 - 2	0.000	0.000	0.000	0.000	0.000
7 - 3	0.000	0.000	0.000	0.000	0.000
8 - 1	0.000	0.000	0.000	0.000	0.000
8 - 2	0.009	0.000	0.000	0.000	0.004
9 - 1	0.073	0.049	0.084	0.162	0.088
9 - 2	0.043	0.003	0.082	0.247	0.064
9 - 3	0.000	1.840	0.000	0.000	0.920
10 - 1	0.150	0.008	0.108	0.074	0.064
10 - 2	0.000	0.017	0.000	0.000	0.006
10 - 3	0.101	0.003	0.108	0.000	0.028
11 - 1	0.000	0.000	0.000	0.000	0.000
12 - 1	0.000	0.000	0.000	0.000	0.000
13 - 1	0.000	0.000	0.000	0.000	0.000
13 - 2	0.017	0.000	0.034	0.042	0.019
13 - 3	0.000	0.000	0.000	0.000	0.000
13 - 4	0.000	0.065	0.000	0.000	0.007
All	0.061	0.028	0.062	0.128	0.064

[a] See Appendix A for a description of the vehicle classes

The average excess ESAL adjustment factors calculated for all the sites considered in this investigation were previously summarized by vehicle configuration and element of the highway system within the state's highway network in Table 5. Few trends are apparent in these adjustment factors as a function of vehicle configuration or highway system. Over-all, a maximum value of 0.266 excess ESALs per vehicle was calculated for Class 7-2 vehicles. This value, however, primarily represents the characteristics of Class 7-2 vehicles at a single site, as 80 percent of the Class 7-2 vehicles in this analysis operated at the Decker site (which, as was previously mentioned, is the only site on a secondary highway considered in this investigation). Class 6-1, 9-1, 10-1, and 10-3 vehicles all have relatively large ESAL adjustment factors (generally greater than 0.03 excess ESALs per vehicle) on all four systems of the highway network. When aggregated at the system level, the largest adjustment factor (0.134 excess

ESALs per vehicle) was determined for the secondary system. Successively lower aggregate adjustment factors were calculated for the non-Interstate NHS, Interstate, and primary systems (0.045, 0.028, and 0.016 excess ESALs per vehicle, respectively). These results are again consistent with the idea introduced above that compliant over standard weight vehicles are used more intensively in intrastate transportation operations than in Interstate operations. The results from the primary system once again are the exception to this observation, and it is important to note that the results reported for this system are based on the analysis of a single site during a single month of enforcement.

Similar to the situation of applying an "average" adjustment factor to data collected from short time intervals, significant over/under estimation of compliant excess ESALs could occur if a single "average" adjustment factor was applied across several sites within a system. While using an average excess ESAL adjustment factor of 0.045 ESALs per vehicle for non-Interstate NHS routes (see Table 5), for example, would understate the compliant excess ESALs per vehicle by only 20 percent at the Stanford site (which has an aggregated adjustment factor of 0.054 ESALs per vehicle), it would understate the situation at the Four Corners/Gallatin site (which has an aggregated adjustment factor of 0.064 ESALs per vehicle) by approximately 40 percent.

3.6 Example Adjustment Factor Applications

The adjustment factors determined above were applied to selected information that was previously collected by STARS and processed through MEARS (specifically, adjustments were made to the data collected from the STARS sites that were enforced during the original STARS evaluation). The intent of this exercise was to qualitatively assess the reasonableness of the adjustment factors, and to determine what, if any peripheral benefits these adjustment factors might offer in the analysis process. Relative to the former task, application of the adjustment factors did not result in any obviously aberrant results, as judged by the authors and pending the concurrence of MDT MCS and Planning personnel. Relative to the latter task, recall that these adjustment factors effectively define the over standard weight vehicle operations that occur at each site in a fully weight compliant environment. Once the MEARS output has been adjusted by these factors, all the remaining overweight vehicle activity indicated by the analysis can conceivably be eliminated by enforcement. Thus, these adjustment factors allow for the calculation of the maximum benefit that can be realized from enforcement in any given situation. This information obviously is of interest in formulating enforcement resource allocation decisions. In some instances, for example, the maximum benefit to be realized may be either so small or so large that the decision whether or not to commit more enforcement resources to a site may be readily apparent. In other cases, the decision may be less clear, and use of more sophisticated decision making tools, such as the Enforcement Planning System proposed in Section 6 of this report, may be necessary.

3.6.1 Percent Overweight Vehicles and Excess ESALs of Pavement Demand

Typical adjustment of the information obtained from MEARS using the factors developed above is illustrated in Table 10. The specific information processed in this example is from the Stanford STARS site for the baseline year of the original STARS evaluation. The unadjusted results of the MEARS analysis indicate that 12.0 percent of the vehicles operating at this site over the year were overweight. After the site specific adjustment factors were applied (as given above in Table 4), 4.8 percent of the vehicles were found to be overweight and non-compliant

Table 10. Typical Adjustments to MEARS Output (Stanford STARS Site, Baseline Year, 2000-2001)

Vehicle Class[a]	No. of Comm. Vehicles	Percent Overweight Vehicles			Excess ESALs			
		Unadjusted	Adjustment Factor	Adjusted	Unadjusted (ESALs)	Adjustment Factor (excess ESALs/veh)	Adjustment (ESALs)	Adjusted
4 – 1	2206	4.3	0.0	4.3	102	0.025	50	52
4 – 2	1776	14.4	0.0	14.4	106	0.013	23	83
5 – 1	12134	1.5	4.3	0.0	108	0.001	6	102
5 – 2	221	0.0	0.0	0.0	0	0.000	0	0
5 – 3	8723	0.0	0.0	0.0	0	0.000	0	0
5 – 4	1090	0.0	0.0	0.0	0	0.000	0	0
6 – 1	5328	13.7	3.7	10.0	1146	0.033	188	957
7 – 1	134	31.3	100.0	0.0	9	0.000	0	9
7 – 2	29	24.1	0.0	24.1	7	0.000	0	7
7 – 3	0	0.0	0.0	0.0	0	0.000	0	0
8 – 1	1432	0.2	0.0	0.2	1	0.000	0	1
8 – 2	1576	1.0	0.0	1.0	10	0.000	0	10
9 – 1	74919	16.9	10.0	6.9	4220	0.055	3957	264
9 – 2	9097	13.8	4.7	9.1	872	0.060	491	381
9 – 3	121	0.0	0.0	0.0	0	0.000	0	0
10 – 1	12936	14.5	15.5	0.0	865	0.037	575	290
10 – 2	417	30.2	26.7	3.5	58	0.011	8	50
10 – 3	224	65.2	65.2	0.0	22	0.008	8	15
11 – 1	0	0.0	0.0	0.0	0	0.000	0	0
12 – 1	36	0.0	0.0	0.0	0	0.000	0	0
13 – 1	1000	0.0	0.0	0.0	4	0.000	0	4
13 – 2	10371	3.1	0.6	2.5	204	0.000	0	204
13 – 3	1485	4.2	4.0	0.2	22	0.000	0	22
13 – 4	5249	4.7	4.3	0.4	84	0.005	29	55
All	150504	12.0	-	4.8	7839	-	5335	2504

[a] See Appendix A for a description of the vehicle classes

during the year. In the original MEARS analysis, 7,839 excess ESALS miles of travel were calculated at this site over the year. After the site specific adjustment factors were applied, 2,504 excess ESAL miles of travel were determined to be caused by over standard weight, non-compliant vehicles. In this case, nominally similar adjusted results (within 27 and 3 percent respectively for percent of overweight vehicles and excess ESALs) were obtained using both the site specific and system average adjustment factors. As may be obvious, this same similarity in outcomes using the two different sets of adjustment factors was not observed across all the non-Interstate NHS/primary sites. A maximum difference of 60 percent was observed in the results when site specific versus system-wide average adjustment factors were used.

3.6.2 Simple Cost Benefit Analysis using Adjusted MEARS Output

The adjustment factors determined above provide essential information for interpreting the cost benefit of past enforcement activities as well as for assessing the potential cost benefit of future enforcement activities. An example of a simple analysis of this kind that utilizes, among other information, the excess ESAL adjustment factors determined above, is presented in Table 11. This analysis is for the enforcement effort at those STARS sites that were subjected to focused enforcement during the initial STARS evaluation. The first step in the analysis was to calculate the cost at each site of the excess pavement damage caused by all over weight vehicles in the traffic stream during the baseline year. These costs were simply calculated using the unadjusted MEARS output for the excess ESAL miles of travel attributable to over weight vehicles at each site, multiplied by the unit cost per ESAL mile of providing these vehicles with highway service (as determined by Stephens and Menuez (2000) in a separate study).

The second step in the analysis was to calculate the cost of that fraction of the excess pavement damage that was associated with the compliant, but over standard weight vehicles in the traffic stream. These costs were calculated by multiplying the ESAL adjustment factors determined above successively by the number of vehicles that passed the site, the extent of the highway network characterized by the site (which is further discussed in the next section of this report), and the unit cost per ESAL mile of providing these vehicles with highway service.

The cost of the excess pavement damage attributable to non-compliant, over standard weight vehicles operating at each site was then determined by subtracting the results of the second step from the results of the first step. As previously mentioned, the resulting values are the maximum savings that could be realized by completely eliminating illegal overweight vehicle operations at these sites. Referring to Table 11, the maximum potential annual savings from enforcement (through avoided pavement damage from over weight vehicles) was estimated to be $1,006,037 at the Four Corners/Gallatin STARS site. The minimum potential annual savings was estimated to be $3,275 at the Arlee STARS site.

In this case, each of these sites was subsequently subjected to some level of focused enforcement the following year, and the effectiveness of this enforcement was simply calculated in terms of the savings realized from the reduction of excess pavement damage that resulted from the focused enforcement effort. The greatest savings in pavement damage during the year of focused enforcement occurred at the Four Corners/Gallatin site, where almost $884,190 in pavement damage from overweight vehicles was averted. This site also had the greatest remaining savings that potentially could be realized from additional enforcement ($121,847).

Table 11. Example Use of Adjustment Factors with MEARS Output: Baseline Year and Year of Focused Enforcement from Initial STARS Evaluation

Site	System[a]	Unadjusted Cost of Overweight Vehicle Operations, Baseline Year ($)	Adjusted Cost of Overweight Vehicle Operations, Baseline Year = Maximum Savings Available from Controlling All Overweight Vehicle Operations ($)	Savings During Year of Targeted Enforcement ($)	Remaining Savings Available ($)	Months of Focused Enforcement During the Year	Savings per Month of Effort ($)
Decker	S	47,080	15,096	6,245	8,851	3	2,082
Miles City East	P	29,578	26,118	-15,556	41,674	1	-15,556
Ryegate	N	173,370	148,094	114,829	33,265	7	16,404
Stanford	N	154,931	86,021	73,524	12,497	10	7,352
Four Corners/ Gallatin	N	1,075,992	1,006,037	884,190	121,847	14	63,156
Townsend	N	122,363	78,041	63,766	14,275	10	6,377
Arlee	N	15,538	3,275	-1,095	4,370	2	-548
Manhattan	I	40,007	17,928	17,115	813	2	8,557
Ulm	I	143,927	105,649	27,646	78,003	4	6,912
All	-	1,802,787	1,486,259	1,170,664	315,595	53	22,088

[a] S – Secondary; P – Primary; N – Non-Interstate NHS; I – Interstate

The least savings in pavement damage occurred at the Miles City East and Arlee STARS sites, where the pavement damage from overweight vehicles actually increased during the year of focused enforcement. These results highlight the variability of commercial vehicle operations through time, and the associated uncertainties in using the methodology developed in this program to characterize these operations. In the case of Miles City East, the adjustment factors for compliant but over standard weight vehicles in the traffic stream could be in error, as they are based upon vehicle operations in a single month of the year. Alternatively, commercial vehicle activity could simply have increased in the year of focused enforcement relative to the previous year, during some or all of the months in which no focused enforcement was conducted. At Arlee, the potential savings that could be achieved from enforcement was small to begin with (only $3,275), relative to the other sites listed in Table 11, and it may have been a poor choice for focused enforcement in the initial evaluation. The original decision to enforce this site is a little more understandable when it is recognized that this decision was made using the unadjusted cost of the pavement damage during the baseline year of $15,538, which is over four times the value of the adjusted cost.

The information in Table 11 can also be used to obtain a simple estimate of the relative cost effectiveness of the enforcement efforts engaged in at the various sites. The savings in avoided pavement damage at each site over the year was divided by the number of months of focused enforcement that it experienced (see Table 11). Based on this parameter, the most cost effective enforcement effort was at the Four Corners/Gallatin site, where $63,156 of savings was realized per month of focused enforcement effort. The lowest rate of return was seen at Miles City East and Arlee, where the pavement damage costs actually increased per month of focused enforcement. The sites with greater cost savings did not always correspond with the sites that offered the greater benefit per unit of enforcement effort. The absolute annual cost savings at the Townsend STARS site of $63,766, for example, exceeded that at Ulm by over 100 percent, but the savings realized per month of focused enforcement was 10 percent lower at Townsend than at Ulm.

While enforcement costs and benefits (quantified a savings in pavement damage) were assumed to be directly proportional to each other in this simple analysis, the actual relationship between these parameters is expected to be much more complex, and it is expected to vary throughout the year and across the state. More thorough determination of these relationships, and developing more sophisticated tools for their use in optimizing allocation of enforcement resources, is discussed in Section 6 of this report.

3.7 Concluding Remarks

Based on the assumption that only weight compliant vehicles operate on the highway during overt weight enforcement activities, factors were developed above to adjust the output from MEARS to account for the presence of these vehicles on the state's highways. These factors effectively indicate the volume of compliant, but over standard weight vehicles that operate on the highway system at each site. Typical adjustment factor analyses were done for those STARS sites that experienced focused enforcement during the initial STARS evaluation. As might be expected, the resulting adjustment factors vary considerably by month, system, site, and vehicle configuration. Therefore, these factors should be determined and applied with as much refinement as is possible relative to these parameters. In recognition of the number of variables involved, the only practical way to develop such a detailed set of adjustment factors would be to automate the manner in which they are calculated. Automation of this activity may be feasible, in that most of the data required for their calculation is already being collected and processed for other purposes. A program simply needs to be set up to identify STARS data that is collected during enforcement activities, copy this data into a separate database, analyze this data to obtain the necessary adjustment factors, and update the existing set of adjustment factors based on this new information. MEARS than would need to be modified to automatically retrieve and apply these factors as appropriate for the analysis that is being conducted. An automated calculation sequence of this kind could be developed and incorporated into the Enforcement Planning System discussed in Section 6 of this report.

Despite their inherent variability, application of the average adjustment factors developed in this investigation by vehicle class and highway system (see Tables 4 and 5) may arguably generate more useable results from MEARS than if no adjustments are made to the current output at all. In using exactly this set of adjustment factors, it is important to remember that the specific data from which they were developed was not uniformly collected throughout the day, the week, or the year. Thus, the resulting adjustment factors could be biased based on these parameters, although the data that was used in these analyses was collected during known periods of peak overweight vehicle operations, and it may inherently represent the more important characteristics of the traffic stream relative to the operations of such vehicles.

The adjustment factors calculated above were used in conjunction with MEARS to estimate the absolute maximum cost savings that can be realized at a STARS site from enforcement. Knowledge of this parameter subsequently allows for some consideration of cost and attendant benefit in assessing the effectiveness of past enforcement activities and in planning future enforcement activities.

4 NORMALIZED OVERWEIGHT VEHICLE PAVEMENT DAMAGE PARAMETER

4.1 General Remarks

A fundamental parameter in the application of STARS related data to vehicle weight enforcement activities is the amount of damage inflicted by overweight vehicles on the highway system. MEARS specifically quantifies pavement damage from the overweight on a vehicle in terms of excess ESAL-miles of travel. In this regard, and as previously mentioned, while this quantity is critical to calculating overweight vehicle impacts, its magnitude by itself does not immediately provide an indication of the relative severity of the over weight problem at a given STARS site. As may be obvious, the absolute magnitude of this parameter can depend on the volume of traffic at a site, as well as on the effectiveness of the weight enforcement at the site. A site could experience a small number of excess ESAL miles of travel, for example, because of an effective enforcement effort at a location that otherwise would have a large number of overweight vehicles, or, there simply may be very few overweight vehicles that ever operate at the site. Therefore, it may be useful if an additional parameter was calculated by MEARS that indicated the relative severity of the excess pavement demand at a site. In this regard, Hanscom (1998) suggested simply using the average excess ESAL per overweight vehicle as a relative damage parameter. While this parameter characterizes the severity of the overweight problem within the population of overweight vehicles, it does not reflect the more general extent of the overweight vehicle problem within the general vehicle population. Perhaps a broader perspective on the relative severity of the over weight vehicle problem at any location would be provided by normalizing the excess pavement demand from overweight vehicles by the total pavement demand from all the vehicles that pass that location.

4.2 Proposed Parameter

The proposed quantity to be used as a normalized measure of the pavement damage from overweight vehicles at a site is the excess ESALs from the overweight vehicles at a site divided by the total number of ESALs from all the vehicles at the site, expressed as a percent. Note that this parameter will complement, rather than replace, the existing pavement damage parameter of excess ESAL miles of travel. The only new quantity required to calculate the new parameter is the estimated total ESALs for all the traffic at the site, as MEARS already calculates the number of excess ESAL from overweight vehicles experienced at the site. While the WIM system is collecting all the axle configuration and weight data necessary to exactly calculate this value, it is computationally simpler, and more then sufficient from an accuracy perspective, to estimate the total ESALs using the average ESAL factors by vehicle configuration that are already determined by MDT for pavement design purposes. The number of vehicles of each configuration can be multiplied by the appropriate average ESAL factor by site, and the results can be summed across all configurations. This sequence of calculations is illustrated in Table 12 for a typical STARS site (in this case, the Four Corners/Gallatin site).

4.3 Results

Typical values of the excess ESALs estimated at a site expressed as a percent of the total ESALS experienced at that site are reported for selected sites in Table 13. As has been the case throughout this investigation, results are reported for the baseline year and the year of focused enforcement for those sites in the original STARS evaluation that were enforced for at least one month during the year of focused enforcement.

Table 12. Typical Calculation of Normalized Excess ESAL Parameter(Four Corners/Gallatin Site, July 26, 2000)

Vehicle Class[a]	Number of Commercial Vehicles in Sample	Average ESAL Factor per Vehicle[b]	Estimated Total ESALs	Excess ESALs from Overweight Vehicles	% of all ESALs from Over Weight
4 - 1	7	0.30	2.10	1.29	61.46
4 - 2	3	0.30	0.90	0.00	0.00
5 - 1	68	0.42	28.68	149.49	100.00
5 - 2	0	0.42	0.00	0.00	0.00
5 - 3	18	0.42	7.59	0.00	0.00
5 - 4	0	0.42	0.00	0.00	0.00
6 - 1	18	0.58	10.48	2.32	22.13
7 - 1	1	1.41	1.41	0.00	0.00
7 - 2	0	1.41	0.00	0.00	0.00
7 - 3	0	1.41	0.00	0.00	0.00
8 - 1	4	0.39	1.58	0.00	0.00
8 - 2	5	0.39	1.97	0.00	0.00
9 - 1	100	1.43	142.61	59.00	41.37
9 - 2	22	1.43	31.37	8.04	25.64
9 - 3	0	1.43	0.00	0.00	0.00
10 - 1	8	1.37	10.94	1.09	9.99
10 - 2	0	1.37	0.00	0.00	0.00
10 - 3	1	1.37	1.37	0.11	7.89
11 - 1	0	1.39	0.00	0.00	0.00
12 - 1	1	1.13	1.13	0.00	0.00
13 - 1	1	1.76	1.76	0.00	0.00
13 - 2	15	1.76	26.33	2.46	9.36
13 - 3	0	1.76	0.00	0.00	0.00
13 - 4	0	1.76	0.00	0.00	0.00
All	272		270.20	223.81	82.83

[a] See Appendix A for description of vehicle classes

[b] Average ESAL factor per vehicle from Bisom (2002)

Referring to Table 13, the reported values for this parameter appear to fulfill its objective of offering a "useful" indication of the relative severity of over weight vehicle impacts within a given traffic stream, independent of the volume of traffic at the site. At Ryegate, for example, the fact that 17,290 excess ESALs from overweight vehicles were experienced in the baseline year is of uncertain significance when taken by itself. When this same level of overweight vehicle demand is re-stated as 13.8 percent of the total ESALs experienced at the site, the relative severity of the overweight problem at the site becomes somewhat more clear. The significance of this value will become even more clear over time, as some experience is gained with its relative magnitudes (i.e., what percentages can be achieved at a well enforced versus a poorly enforced site).

Table 13. Typical Values, Excess ESALs as a Percent of Total ESALs at a Site

Site	System[a]	Months of Focused Enforcement During the Year	Percent Excess ESALS, Baseline Year	Percent Excess ESALS, Year of Focused Enforcement
Decker	S	3	9.7	7.7
Miles City East	P	1	8.4	18.2
Ryegate	N	7	13.8	3.4
Stanford	N	10	6.3	1.3
Four Corners/ Gallatin	N	14	63.8	7.5
Townsend	N	10	11.4	5.3
Arlee	N	2	1.2	0.9
Manhattan	I	2	2.5	0.4
Ulm	I	4	5.2	3.8

[a] S – Secondary; P – Primary; N – Non-Interstate NHS; I – Interstate

In the baseline year, this parameter ranged from 1.2 to 63.8 percent. Relative to interpreting these magnitudes, note once again that these sites were identified for enforcement due to the large over weight vehicle impacts they were experiencing; thus, these magnitudes may in some way be “typical’ of severe overweight situations. In the following year, when focused enforcement was engaged in for a minimum of one month at each site, this parameter dropped to 0.4 to 18.2 percent. Despite the general decrease in the magnitude of this parameter in the year of focused enforcement relative to the baseline year, changes in this parameter do not appear to be directly proportional to the level of enforcement effort at a site. The Four Corners/Gallatin site had the greatest severity of overweight vehicle activity during the baseline year (excess ESAL parameter of 63.8 percent), and it was selected and received the greatest level of enforcement during the following year. Conversely, only 1.2 percent of the ESALs at the Arlee site were from overweight vehicles. As previously noted, and as further reinforced by the relatively small magnitude of this parameter, Arlee may have been a marginal choice for focused enforcement during the initial STARS evaluation.

5 EXTENT OF VEHICLE OPERATIONS CHARACTERIZED BY EACH STARS SITE

5.1 General Remarks

Though determined at discrete points along the state highway system, the overweight vehicle profile obtained at each STARS site is obviously representative of the profile of vehicles that are operating over some portion of the state's highway network. Similarly, while engaged in at a single location, an enforcement activity obviously influences overweight vehicle operations over some extended portion of the highway network. In the initial STARS evaluation, each STARS site was generally assumed only to characterize those vehicles that traversed the highway segment that contained the site, itself. The end points of these highway segments were defined by the closest intersection of the route containing the STARS site with another major highway, Interstate, or state line. In some cases, the profile was assumed to extend beyond the first adjacent junction upstream or downstream of the site, if traffic on the same route remained constant through these junctions. A summary of the segments of the highway system assigned to each STARS site in this fashion is presented in Table 14. These segments were subsequently used in calculating the absolute impact that any changes in overweight vehicle operations, as identified from the STARS data, would have on the damage sustained by the highway infrastructure.

In most cases, the vehicle weight profiles obtained from the STARS sites can be applied across a greater extent of the highway system than the segments identified above. The majority of the end points of the highway segments assigned above are neither the origin or the ultimate destination of the commercial vehicles operating on that segment of highway. In a sparsely populated state such as Montana, intersections of major highways often occur in sparsely populated areas. Correspondingly, a large majority (if not all) commercial vehicles simply pass through such intersections on their way to their ultimate destinations. The major uncertainty that remains in such cases is the specific route that these vehicles follow when they leave such intersections, as this information is not systematically collected (e.g., through origin destination surveys). However, once again due to the sparse population and large geographic extent of the state, travel paths can often be inferred based on the few routes that are available between the state's widely spaced population centers. When some judgment is used in this regard, coupled with traffic volume information by route (which is available for all the segments of the state highway system), it is possible to determine to some degree where the vehicles that pass each STARS site have also traveled.

If, following the broad methodology outlined above, it can be determined where vehicles came from before they reached a segment of highway with a STARS site, and/or where they went after they traversed a segment of highway with a STARS site, their impacts, as identified at the STARS site, can be assessed across a greater extent of their total travel on the state's highway system than is currently being done.

5.2 Methodology

The method used to determine the extent of the highway system traversed by the vehicles passing each STARS site was inherently subjective in nature. While quantitative information is available on the net volume of traffic on each route at an intersection (MDT, 2003), this

Table 14. Extent of Commercial Vehicle Operations Impacted by Each STARS Site, Initial STARS Evaluation

WIM Site	Route	System	From:		To:		Mileage[a]
Townsend	US 287	Non-Interstate NHS	I-15	Helena	I-90	W. of Three Forks	62
Comments[b]: Truck volumes stay consistent through intersection with US 12 in Townsend							
Decker	Hwy 314	Secondary	US 212	W. of Busby	MT/WY Border		44
Manhattan	I-90	Interstate	US 287	W. of Three Forks	SR 85/US 191	Belgrade	23
Arlee	US 93	Non-Interstate NHS	I-90	W. of Missoula	SR 200	Ravalli	27
Four Corners/ Gallatin	US 191	Non-Interstate NHS	I-90	Belgrade	MT/ID Border		98
Comments[b]: Truck volumes stay consistent through intersection with US 287 and US 20 (West Yellowstone).							
Galen	Hwy 273	Secondary	I-90	S. of Deer Lodge	SR 1	E. of Anaconda	11
Broadview	SR 3	Non-Interstate NHS	US 12	N. of Lavina	I-90	Billings	47
Miles City East	US 12	Primary	I-94	E. of Miles City	SR 7	Baker	77
Ulm	I-15	Interstate	US 87/SR 3	Great Falls	US 12	Helena	86
Comments[b]: Low truck volumes on US 287 (S. of Craig).							
Ryegate	US 12	Non-Interstate NHS	US 191	Harlowton	SR 3	Lavina	45
Stanford	US 87	Non-Interstate NHS	I-15	Great Falls	US 191	W. of Moore	88
Comments[b]: Low truck volumes on US 89 (E. of Belt) and SR 80 (Stanford).							
Fort Benton	US 87	Non-Interstate NHS	I-15	Great Falls	US 2	Havre	112
Comments[b]: Low truck volumes on SR 80 (Fort Benton).							
Havre East	US 2	Non-Interstate NHS	US 87	Havre	SR 24	Glasgow	158
Comments[b]: Low truck volumes on SR 66 (Fort Belknap) and US 191 (Malta).							
Paradise	SR 200	Primary	SR 135	S. of Paradise	SR 28	Plains	7
Culbertson	SR 16	Non-Interstate NHS	SR 200	Sidney	SR 5	Plentywood	82
Comments[b]: Truck volumes stay consistent through intersection with US 2 (Culbertson).							
Lima	I-15	Interstate	SR 41	Dillon	MT/ID Border		64

[a] Mileage determined from Montana 1998-99 Official State Highway Map and 1997 MDT Road Log.

[b] Truck volumes determined from MDT 1999 Montana Rural Traffic Flow Map.

information alone is insufficient to uniquely determine the routes by which any specific vehicle enters and exits the intersection. In many cases, however, some idea on how traffic moves through such intersections can be inferred from the expected flow of goods and services between and through population centers in Montana. In this regard, a broad summary of the assumptions made regarding such flows through each STARS site is presented in Table 15. These broad flows were used as a guide to assign the total volume of traffic reported on the

Table 15. General Traffic Flow Assumed for STARS Route Analysis

STARS Site	General Traffic Flow	
	Dominant	Lesser
Arlee	Missoula – Flathead Valley	-
Broadview	Billings – Great Falls	Billings - Lewistown
Culbertson	Sidney - Plentywood	-
Decker	Decker-Busby	-
Fort Benton	Great Falls - Havre	-
Four Corners/Gallatin Gateway	Bozeman/Belgrade - West Yellowstone	“Through” traffic between southwest MT and ID
Galen	Local traffic only	-
Havre East	Northeastern MT - Great Falls	“Through” traffic on U.S. 2 across Northern MT Havre-Billings
Lima	“Through” traffic on I-15	
Manhattan	Billings – Butte – Bozeman - Missoula	“Through” traffic on I-90
Miles City East	Miles City to Baker	West Central MT to Baker
Paradise	I -90 – NW MT and Central ID	-
Ryegate	Billings – Great Falls	Billings - Lewistown
Stanford	Billings – Great Falls	Lewistown - Great Falls
Townsend	South Central MT – Helena	South Central MT – North Central MT
Ulm	Helena – Great Falls	“Through” traffic on I-15

routes converging at an intersection to specific paths, traceable backwards or forwards through a given STARS.

The STARS site at Arlee offers a good example of the implementation of the general route analysis described above. A map of the state's highway network in this region is reproduced in Figure 5. In a global sense, commercial vehicle traffic moving through Arlee was primarily assumed to be involved with the local flow of goods and services between Missoula and the communities of Kalispell, Whitefish, and Columbia Falls clustered on the north end of the Flathead Valley. All of the communities in between these population centers are small in size, and engage in only limited economic activity. Therefore, only a small percentage of the traffic traveling north out of Missoula was assumed to have these communities as their final destination, and these communities were further assumed to be the origin of only a small fraction of the commercial traffic observed to the north of them. These conclusions are not inconsistent with the traffic data collected along these routes. Virtually the same volume of commercial vehicles, for example, is reported to be operating on route N-5 north and south of Arlee, based on the average ADT at these locations from 2001 to 2003 (MDT, 2003). It is important to note, however, that the data available from MDT simply indicate that the same number of vehicles is operating north and south of town, not if they are identically the same vehicles. In this case, a broader knowledge of the nature of the economic activity in the area would confidently lead to the conclusion that, with very few exceptions, identically the same vehicles are operating north and south of town, having simply passed through Arlee on their way to somewhere else. Thus, 100 percent of the traffic that passed the STARS site at Arlee was assumed to have traveled on the entire segment of N-5 between Missoula and Ravalli.

The first major intersection north of Arlee, at Ravalli, offers a greater challenge relative to deciding where vehicles passing through this intersection either came from (i.e., did they already come through the WIM site at Arlee) or where they are headed toward (are they going to pass through the WIM site at Arlee). These decisions can be simplified, once again, based on some knowledge of the level of economic activity in Ravalli, itself. Ravalli is a community of less than 1,000 people (MDT, 2004), and it is neither the origin of, or the destination for, the majority of the commercial vehicles operating in the area. Thus, the traffic volumes reported for the three routes intersecting at Ravalli are primarily for vehicles that travel through Ravalli. If the volume of commercial traffic on each route is evenly split in each direction of travel, the pattern of flow through the intersection can be uniquely determined based on the requirement that the volume of traffic that enters and exits the intersection must be equal. In this case, in the absence of information regarding traffic volumes by direction of travel, an even split in the reported traffic volume by direction was assumed. In the resulting flow analysis, it was found that approximately 88 percent of the traffic that passes through the WIM site on N-5 at Arlee also travels on the segment of N-5 north of Ravalli (with the majority of these vehicles traveling through and past Polson, the next major intersection to the north), while approximately 10 percent of the traffic that passes the WIM site was also found to have traveled on route P-6 west of Ravalli. Note that a small percentage of the vehicles that pass the WIM site at Arlee (2 percent) were assumed to end their trip at Ravalli.

Figure 5. Map of Routes in the Vicinity of the Arlee STARS Site

Analysis of the probable routes traveled by the vehicles that pass each STARS site continued as outlined above, until one of the following conditions was encountered:

(1) the number of vehicles that passed the STARS site whose route was being traced dropped below a threshold value, which in this case was somewhat arbitrarily assumed at 30 percent of the total number of vehicles that passed the site,
(2) in the opinion of the analyst, the route of the vehicles that passed the STARS site could no longer be reliably traced, or
(3) the route of the vehicles that passed the STARS site entered the domain of influence of another STARS site.

It was believed that by using these criteria, the positive impacts of any changes in overweight vehicle operations that resulted from a enforcement activity would still be understated in these analyses. Relative to the first condition above, for example, further travel of the 10 percent of the traffic that passed through the WIM site at Arlee that also traveled on route P-6 between Ravalli and the intersection with route P-35, was not traced past the intersection of routes P-6 and P-35. The vehicles traveling on this segment of roadway definitely also traveled on a connected segment of roadway to the west, as the intersection of route P-6 and P-35 is not in a community. Nonetheless, in light of 1) the increasing uncertainties in what travel routes are followed by a vehicle as the analysis moves further away from a given STARS site and 2) the decreasing magnitude of the impacts to be assessed, the decision was made to ignore any further impacts past this point.

Relative to the second condition given above for terminating a STARS site route analysis, vehicles that travel through some STARS sites either enter or pass through an intersection and/or a population center that offers too many alternative actions for their individual travel paths to be further determined. In such situations, the impact analysis was simply terminated at this point. Once again, using Arlee as an example, the route analysis north of Arlee was terminated at Kalispell, even though many of the vehicles that travel past the Arlee WIM site are also expected to travel over the highway network that connects Kalispell to Columbia Falls and Whitefish, and beyond. Too many assumptions are required relative to route choices for trips between Kalispell and the communities to the north, as well as regarding those trips whose origin and destination might be Kalispell, to reasonably trace vehicle travel any further past this point. For similar reasons, the route analysis south of Arlee was terminated at Missoula.

The route analysis performed for a given WIM site was also terminated when the next route to be traveled by a vehicle was in the obvious area of influence of an adjacent WIM site (the third condition listed above). In assessing commercial vehicle operations statewide, it is essential that such operations only be assessed once for any given vehicle on any given segment of highway. In central Montana, for example, a majority of the vehicles traveling between Billings and Great Falls are expected to pass through the Broadview, Ryegate, and Stanford STARS sites (see Figure 6). Thus, while information collected at the Stanford STARS site will be indicative of the traffic on the segment of roadway between Harlowton and Lavina, vehicle operations on this segment of highway will be more accurately determined from the data collected immediately along this segment of highway at the Ryegate STARS site. Correspondingly, infrastructure impacts from commercial vehicles traveling between Harlowton and Lavina will be more accurately and comprehensively assessed using data directly from the Ryegate STARS site.

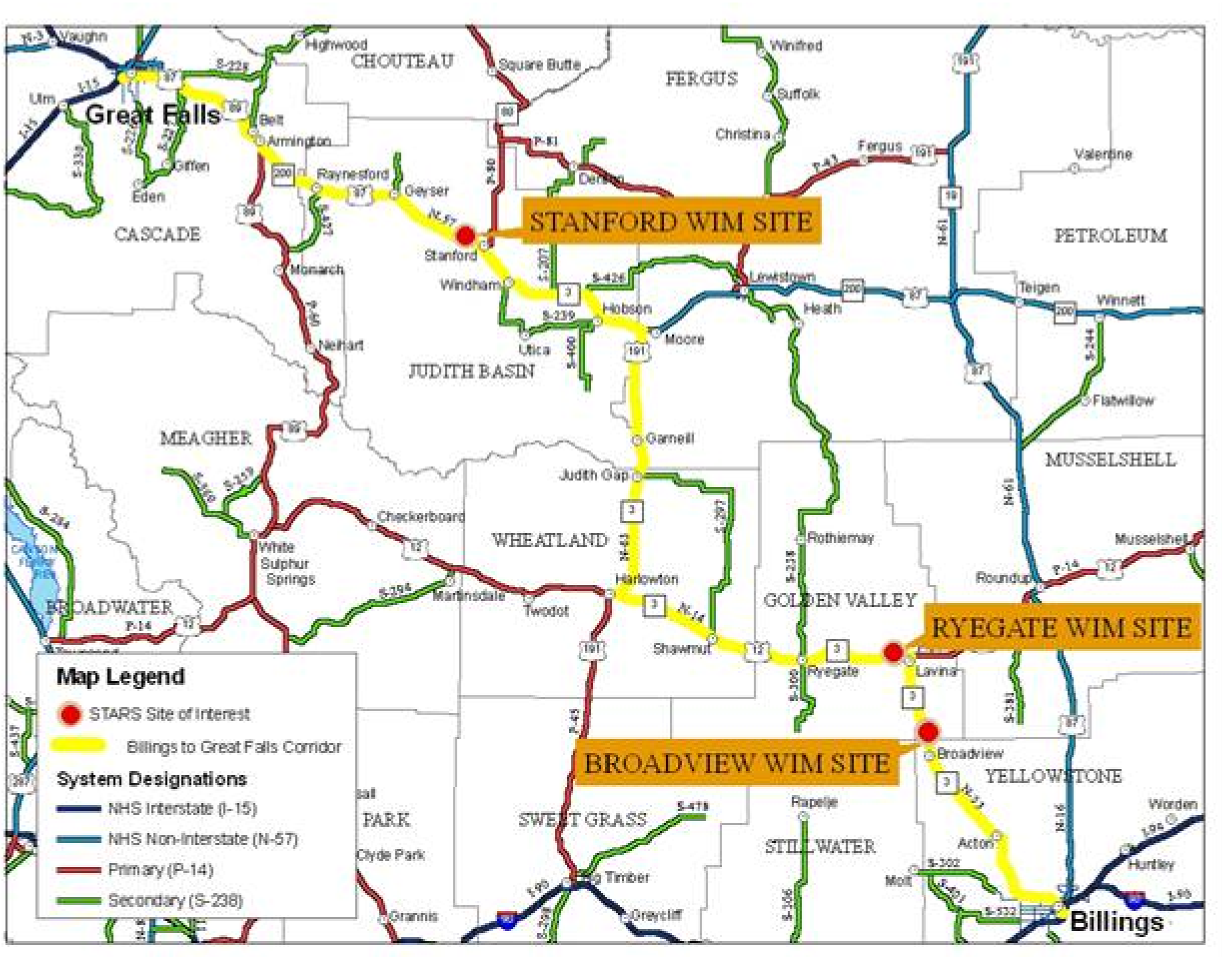


Figure 6. Map of Routes in the Vicinity of the Broadview, Ryegate, and Stanford STARS Sites

The approach described above for determining the extent of the highway system whose operations are characterized by the data collected by STARS is most accurate when system wide analyses are being done that look comprehensively at the data collected at all STARS sites; it is less accurate when more localized analyses are being performed using the data collected at individual sites. The complicating factor in moving between system wide and individual site analyses is the capture of information on the same vehicle by more than one STARS site. Returning to the flow of traffic mentioned above between Billings and Great Falls, for example, if an enforcement activity is engaged in at the Stanford STARS site, its influence is expected to extend to vehicle operations between Harlowton and Lavina (where the Ryegate STARS site is located) and to operations between Lavina and Billings (where the Broadview STARS site is located). If the impact of this enforcement activity is evaluated only using the data from the Stanford STARS site, its effects will be underestimated, as following the current methodology, the data from the Stanford site is only assumed to cover operations on the highway network up to the boundary with the coverage provided by the Ryegate STARS site.

One approach to addressing the above situation is to include in any local analyses the data collected from adjacent STARS sites. In the case of assessing impacts from an enforcement activity at the Stanford site, for example, the analysis should include the data collected at the Ryegate and Broadview STARS sites. The problem associated with this approach is that vehicle activity at the Ryegate and Broadview STARS sites may be influenced by more factors than simply the enforcement environment at the Stanford site. A second approach to generally address this situation is to perform a second route analysis for each site that ignores the presence of adjacent STARS sites. The results of these route analyses would be used when overweight vehicle impacts are to be analyzed locally using the data from a single STARS site.

Note that throughout the above analyses, a second perspective on the results can be obtained by considering the percentage of traffic on any given route that is assumed to have also traveled through a given STARS site. Once again, using Arlee as an example, it was previously stated that approximately 10 percent of the traffic that passed the Arlee STARS site also traveled on route P-6 between Ravalli and the intersection with Route P-35. Based on this conclusion, it can further be calculated (based on the traffic data) that 44 percent of the commercial vehicles on route P-6 between Ravalli and the intersection with route P-35 also traveled past the Arlee STARS site. Each statement offers an obviously different but equally meaningful characterization of the assumed flow of commercial vehicle traffic past the Arlee STARS site.

The final results of the above analyses were aggregated for each STARS site by calculating an "equivalent" geographic extent of highway system operations that are characterized by the data collected at each STARS site. These aggregated mileage values were calculated by multiplying the length of each route segment adjacent to a given STARS site by the percent of vehicles that passed the STARS site that also traveled on that segment of roadway. These contributions were summed up to obtain a single revised mileage value for each site.

5.3 Results

The results of the STARS route analyses described above are summarized in Table 16. These analyses were completed for the 16 STARS sites included in the original STARS evaluation Information provided in the Table 16 includes the network mileage assigned to each STARS site in the original STARS evaluation, the revised mileage determined in this analysis, and the routes and traffic flows used in this analysis. At Ryegate, for example, the revised mileage was calculated as the sum of 100 percent of the 45 miles of highway from Lavina to Harlowton that contains the Ryegate STARS site, 10 percent of the adjoining 21 miles of highway from Lavina to Roundup (i.e., 10 percent of the vehicles on this segment of highway were presumed to also travel past the Ryegate STARS site), 4 percent of the adjoining 44 miles of highway from Big Timber to Harlowton, and 12 percent of the 59 miles of highway from Harlowton to White Sulfur Springs.

In recognition of the obvious spatial nature of this information, the results of these route analyses are also graphically portrayed for several sites, as indicated in Table 16. The graphical presentation of the results has also been annotated with the traffic data (commercial vehicle

Table 16. Extent of Commercial Vehicle Operations Characterized by Each STARS Site

Site	Original Mileage	Revised Mileage	Route No.	Segment of Route	Approx. Length of Segment (miles)	% of Vehicles that Pass STARS Site that also Travel on this Segment of Roadway	% of Vehicles on this Segment of Roadway that also Pass this STARS Site
Arlee (Figure 7)	27	96	N-5	Missoula to Ravalli	28	100	100
			N-5	Ravalli to Ronan	19	88	90
			N-5	Ronan to Polson	12	83	85
			N-5	Polson to Kalispell	51	35	67
			P-52	Polson to Kalispell	51	39	67
			P-6	Ravalli to P35	31	10	44
Broadview	47	47	N-53	Billings to Lavina	47	100	100
Culbertson (Figure 8)	82	99	N-22	Culbertson to Froid	14	100	100
			N-22	Froid to Plentywood	32	76	100
			P-30	Plentywood to State Line	24	4	12
			N-34	Plentywood to State Line	16	45	83
			P-22	Plentywood to Scobey	41	15	46
			N-62	Sidney to Culbertson	38	56	88
			N-1	State Line to Culbertson	22	19	25
			N-20	Glendive to Sidney	51	41	35
Decker	44	44	S-314	WY-MT Line to Busby	44	100	100

Table 16. Continued

Site	Original Mileage	Revised Mileage	Route No.	Segment of Route	Approx. Length of Segment	% of Vehicles that Pass STARS Site that also Travel on this Segment of Roadway	% of Vehicles on this Segment of Roadway that also Pass this STARS Site
Fort Benton	112	112	N-10	Great Falls to Havre	112	100	100
Four Corners/ Gallatin	98	98	N-12	State Line to W. Yellowstone	9	100	100
			N-50	W. Yellowstone to Four Corners	82	100	100
			N-85	Four Corners to Belgrade	7	100	100
Galen	11	11	S-273	Local Traffic	11	100	100
Havre East (Figure 9)	158	163	N-1	Havre to Fort Belknap	48	100	100
			N-1	Fort Belknap to Malta	43	60	95
			N-1	Malta to Glasgow	71	51	86
			P-66	Fort Belknap to N-61	50	20	97.5
			N-1	Shelby to Havre	101	43	85
			N-10	Fort Benton to Havre	71	24	40
Lima (Figure 10)	64	64	I-15	State Line to Dillon	64	100	100
Manhattan (Figure 11)	23	23	I-90	Three Forks to Belgrade	23	100	100
Miles City East	77	77	P-2	Miles City to Baker	77	100	100
Townsend	62	62	N-8	Helena to Three Forks	62	100	100
Ulm	86	86	I-15	Helena to Great Falls	86	100	100

Table 16. Concluded

Site	Original Mileage	Revised Mileage	Route No.	Segment of Route	Approx. Length of Segment	% of Vehicles that Pass STARS Site that also Travel on this Segment of Roadway	% of Vehicles on this Segment of Roadway that also Pass this STARS Site
Paradise (Figure 12)	7	73	P-6	Jct P-35 to Plains	8	100	100
			P-35	St. Regis to Jct P-6	21	59	40
			P-36	Jct P-6 to Jct N-5	47	29	39
			P-6	Plains to Thompson Falls	26	68	58
			P-6	Thompson Falls to Jct w/ P-56	18	64	55
			P-6	Jct w/ P-56 to State Line	10	48	70
			P-56	Jct w/ P-6 to Jct w/ N-1	34	15	30
Ryegate (Figure 13)	45	56	N-14	Lavina to Harlowton	45	100	100
			P-14	Roundup to Lavina	21	10	90
			P-45	Big Timber to Harlowton	44	4	5
			P-14	Harlowton to White Sulfur	59	12	52
Stanford (Figure 14)	88	118	N-60	Belt to Great Falls	24	93	95
			N-57	Geyser to Belt	21	94	100
			N-57	Eddies Corner to Geyser	44	100	100
			N-57	Lewistown to Eddies Corner	18	31	90
			N-63	Harlowton to Eddies Corner	40	65	90

Figure 7. STARS Route Analysis: Arlee

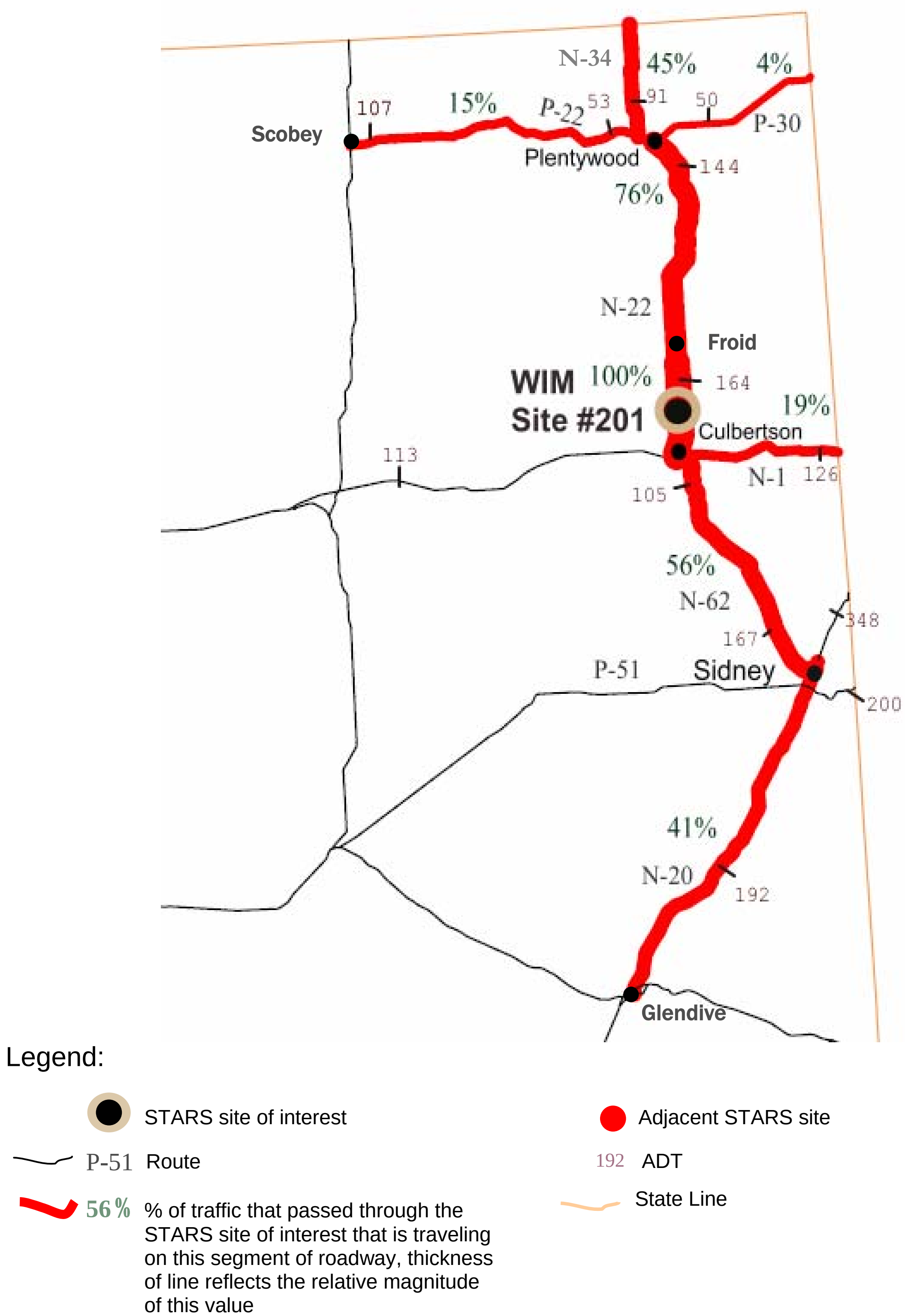
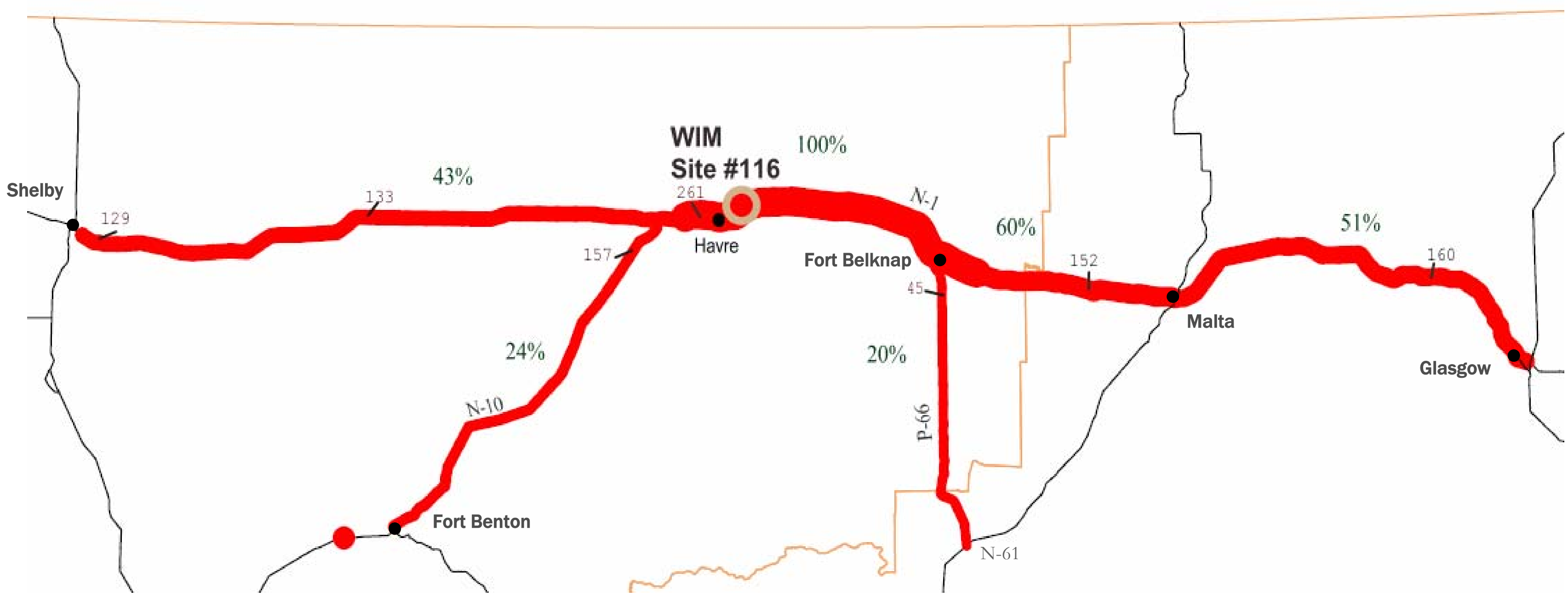


Figure 8. STARS Route Analysis: Culbertson



Legend:

STARS site of interest

Adjacent STARS site

P-66 Route

133 AADT

43% % of traffic that passed through the STARS site of interest that is traveling on this segment of roadway, thickness of line reflects the relative magnitude of this value

County/State Line

Figure 9. STARS Route Analysis: Havre East

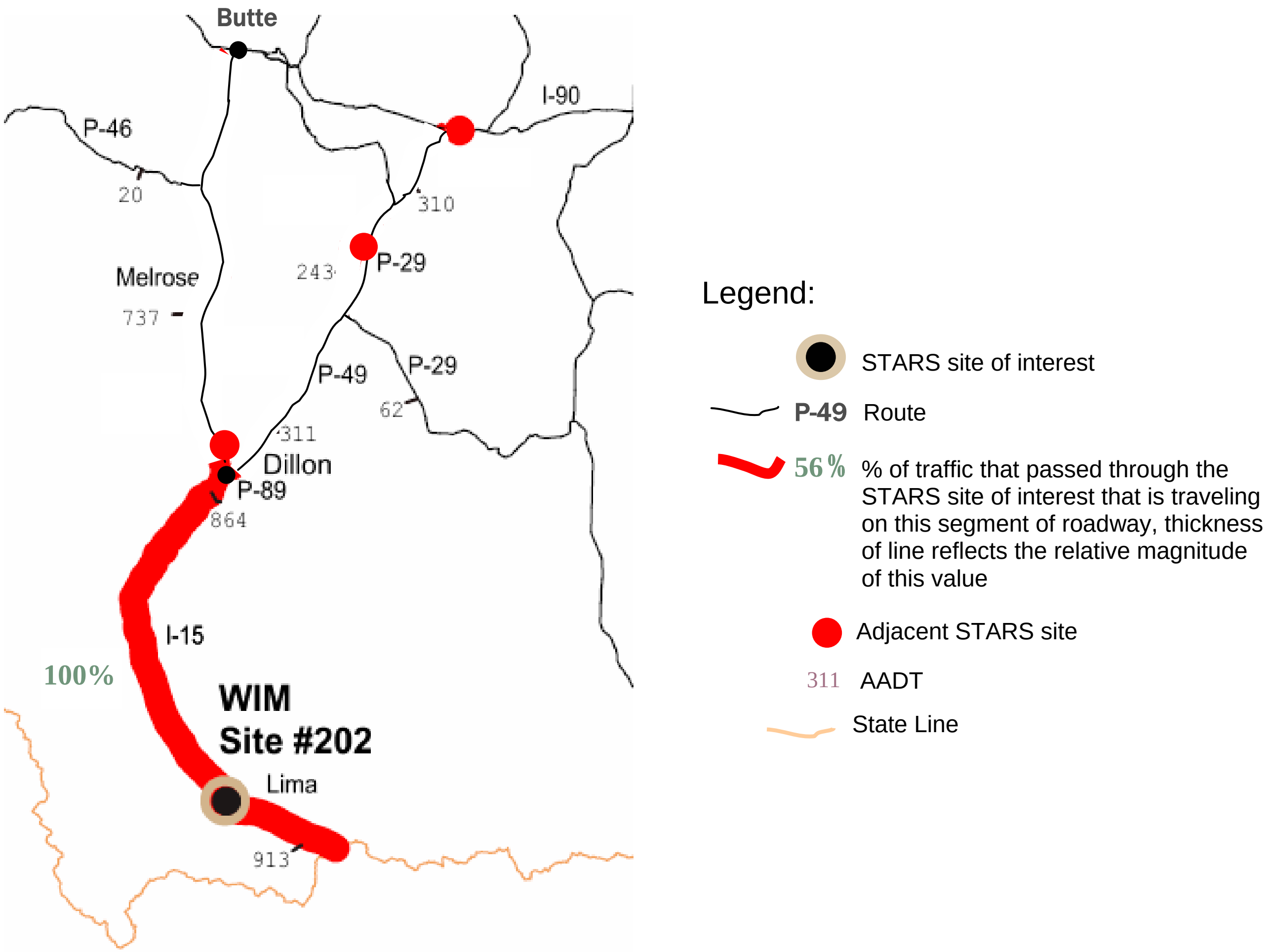


Figure 10. STARS Route Analysis: Lima

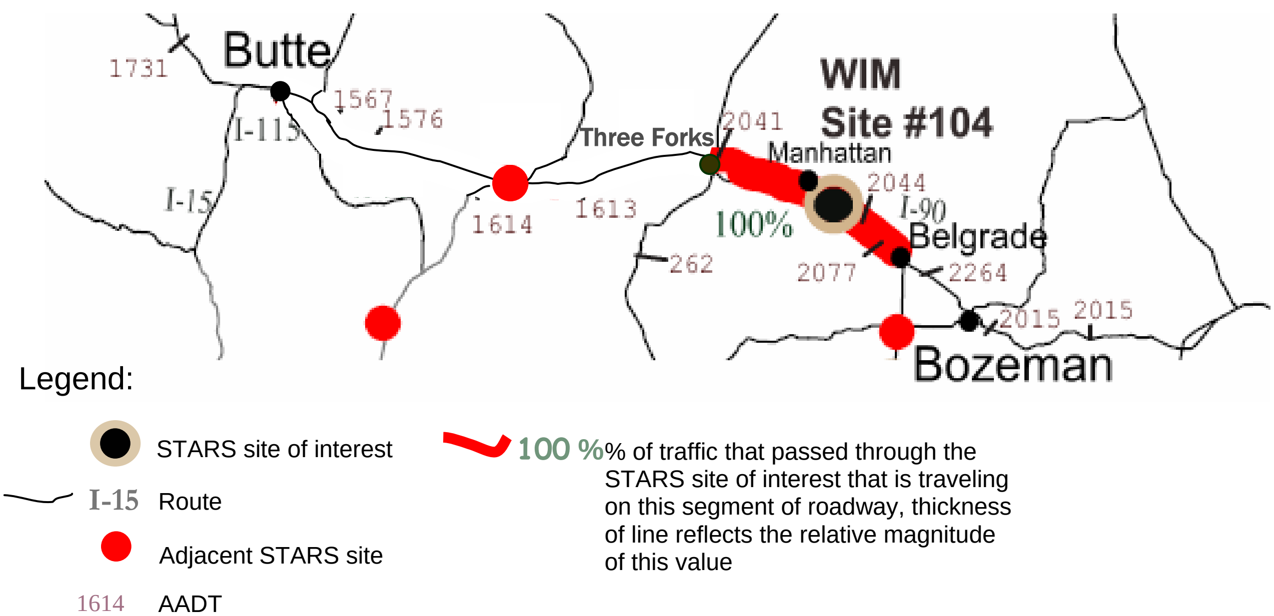


Figure 11. STARS Route Analysis: Manhattan

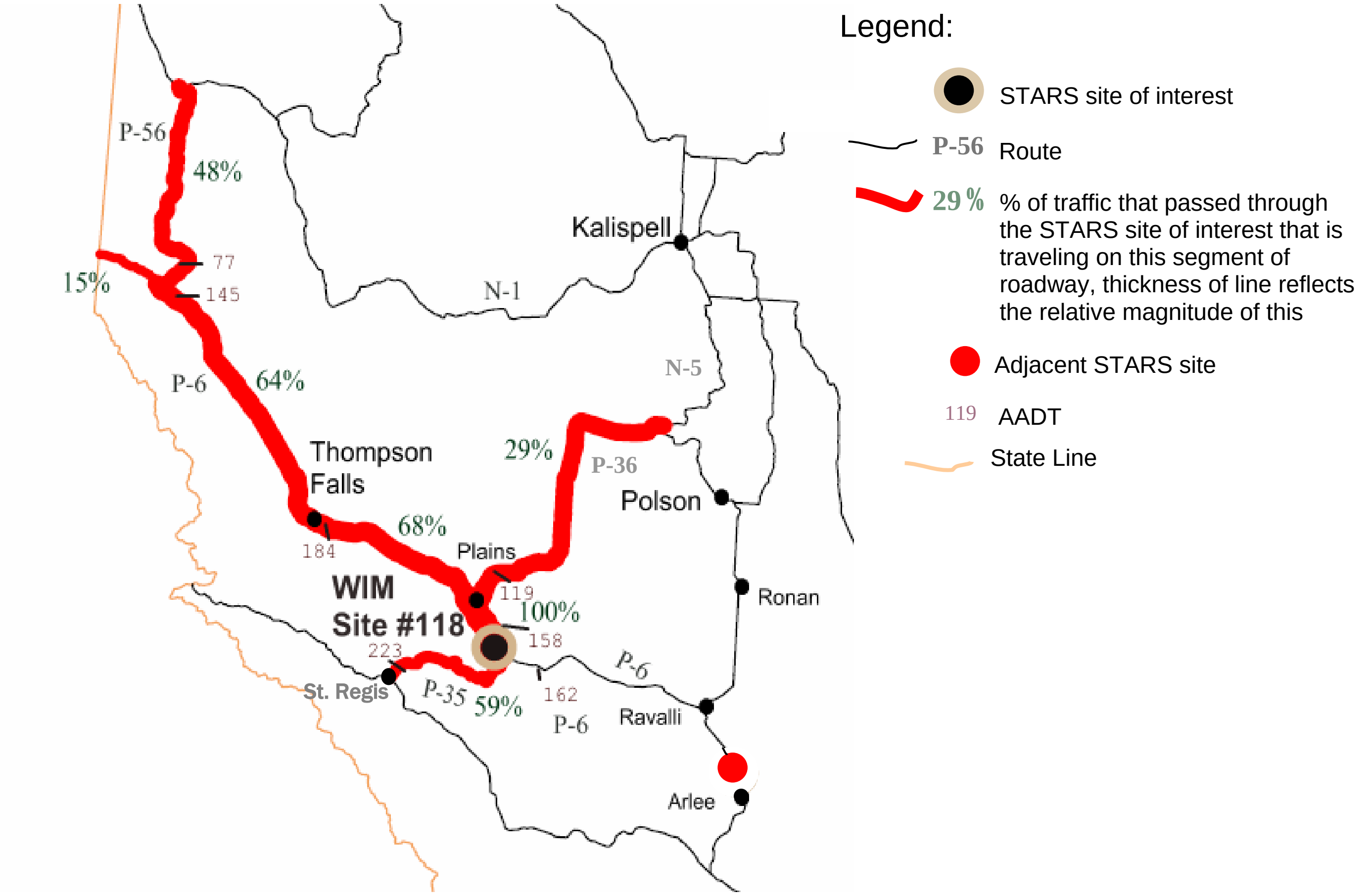


Figure 12. STARS Route Analysis: Paradise

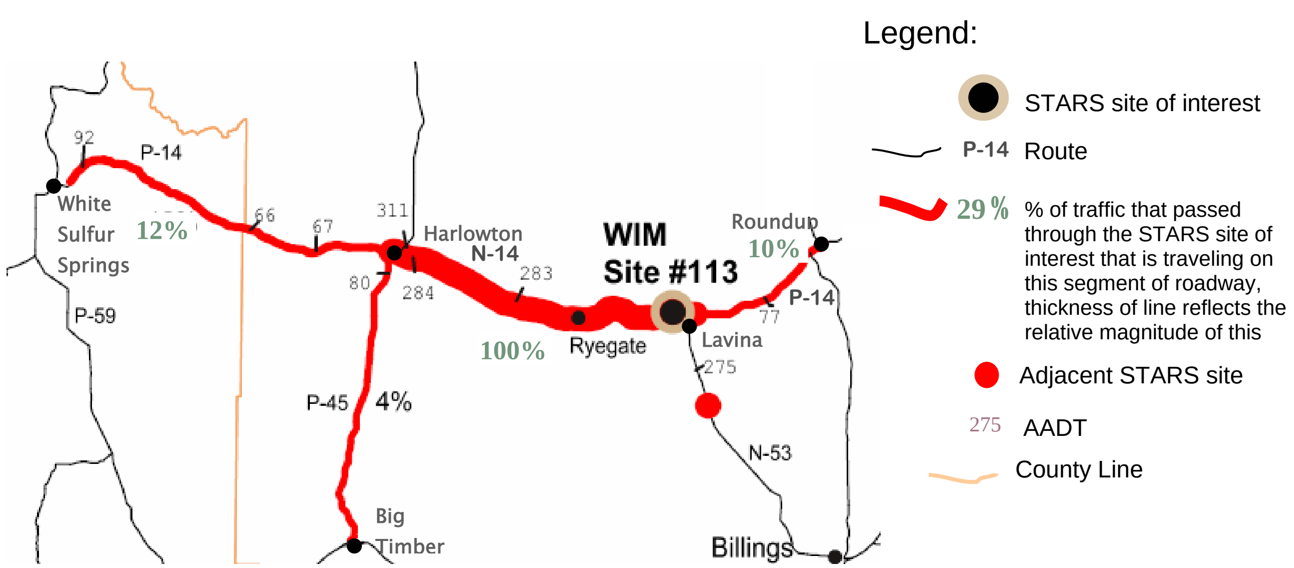


Figure 13. STARS Route Analysis: Ryegate

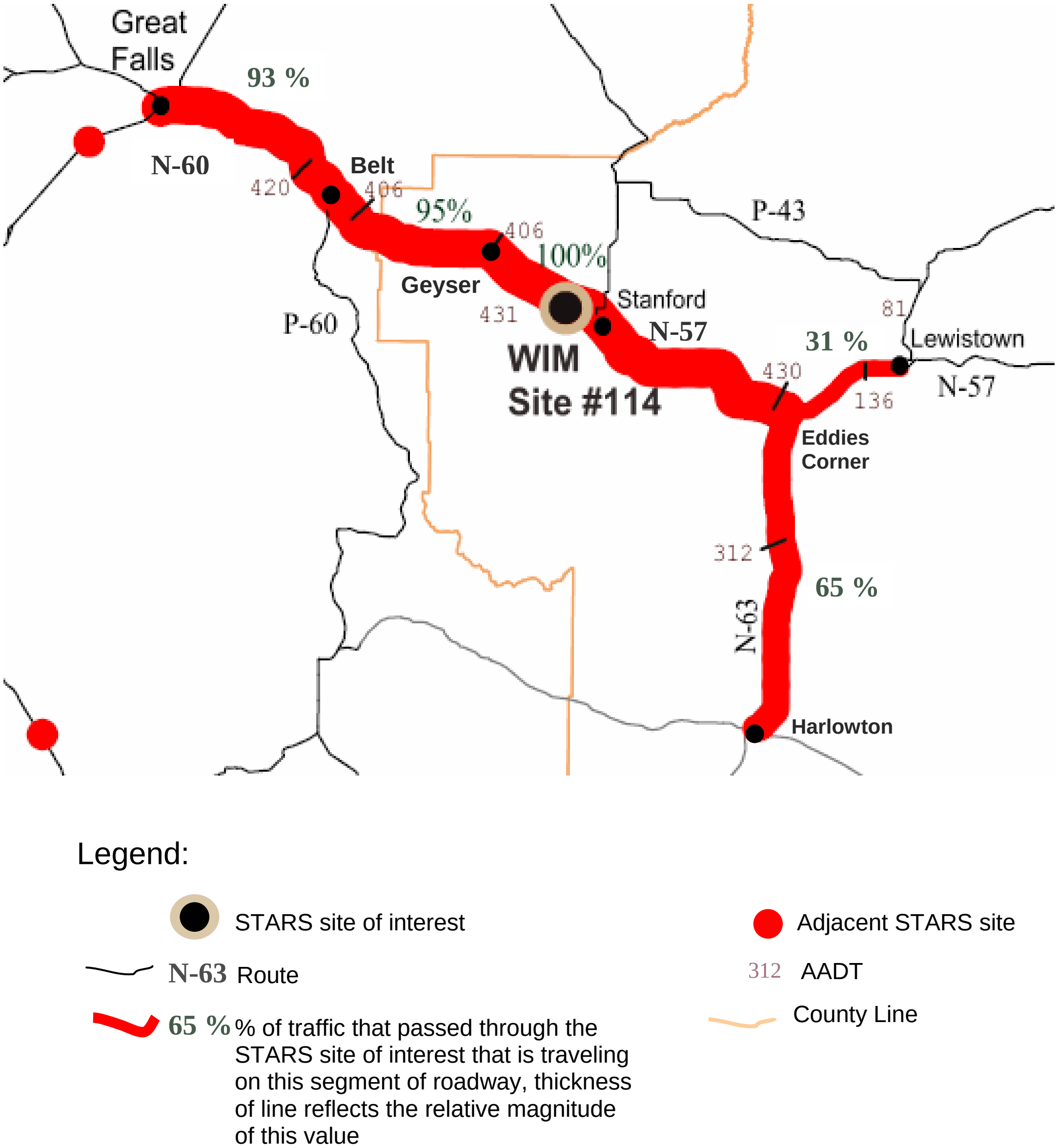


Figure 14. STARS Route Analysis: Stanford

ADT) that was used in part of the analysis. A graphical display of the results of these analyses is also available in the prototype interface for the proposed Enforcement Planning System described in Section 6 of this report. In light of the somewhat subjective nature of their development, the results of these analyses need to be closely scrutinized by MDT and revised as necessary.

6 PROPOSAL TO DEVELOP AN ENFORCEMENT PLANNING SYSTEM

6.1 General Remarks

The value of focusing weight enforcement efforts at particular locations and times based on STARS data has been demonstrated (Stephens, et al, 2003, Stephens and Carson, 2005). Cost-benefit and other analysis resulted in recommendations for the use of STARS, enhancement of MEARS and further development of these tools for weight enforcement use. Among the recommendations for future work was that consideration be given to integrating enforcement level of effort information and pavement damage costs to improve allocation of enforcement resources.

Enforcement resource allocation could be well supported by development of an *Enforcement Planning System* (EPS). The EPS would interface with existing MDT systems to support the user in making enforcement assignments to maximize effectiveness. Correlation of historical enforcement effort with reduction in pavement damage costs would form the basis of computer models that would be used for evaluating enforcement plans. These models would then use WIM and other data from MEARS to predict outcomes for assigning officers in a "what-if" mode. Coupled with search algorithms, the models could also be used to generate assignment recommendations in a "what's-best," or optimization, mode. Users would interact with the EPS through an intuitive, map-based, graphical interface. Finally, the EPS would be developed to be easily adapted by other states.

The remainder of this section documents the vision for the enforcement planning system, beginning with an overview of the decision environment and the envisioned use of the EPS. Next, requirements and the conceptual design for database, models, search algorithms and the user interface are discussed. The section concludes with a description of a prototype map-based user interface and an outline of the steps necessary to develop the EPS.

6.2 EPS Use

Assigning enforcement personnel to locations at specific times is a planning problem with similarities to and differences from many others. The geographical distances between assignments distinguish this problem from many other manpower scheduling problems, such as medical personnel scheduling where the location of the service is fixed. The New York City CompStat (Computerized Statistics) system (OMAP NYPD, 1999 and NYPD CompStat Unit, 2005) effectively combines data, models and a map-based graphical interface to allocate enforcement resources. CompStat has also been adopted by many major cities since the project's inception in 1994.

As demonstrated in earlier studies (Stephens, et al., 2003, Stephens and Carson, 2005), information from STARS can be effectively used to assign enforcement resources. The Motor Carrier Services Division of MDT currently uses MEARS reports to develop annual enforcement plans based on historical overweight vehicle activity. The interactive Enforcement Planning System envisioned here would take the process to the next level by providing a tool to:

Obtain and visualize useful information,
Evaluate alternative plans, and
Request computer-generated plans.

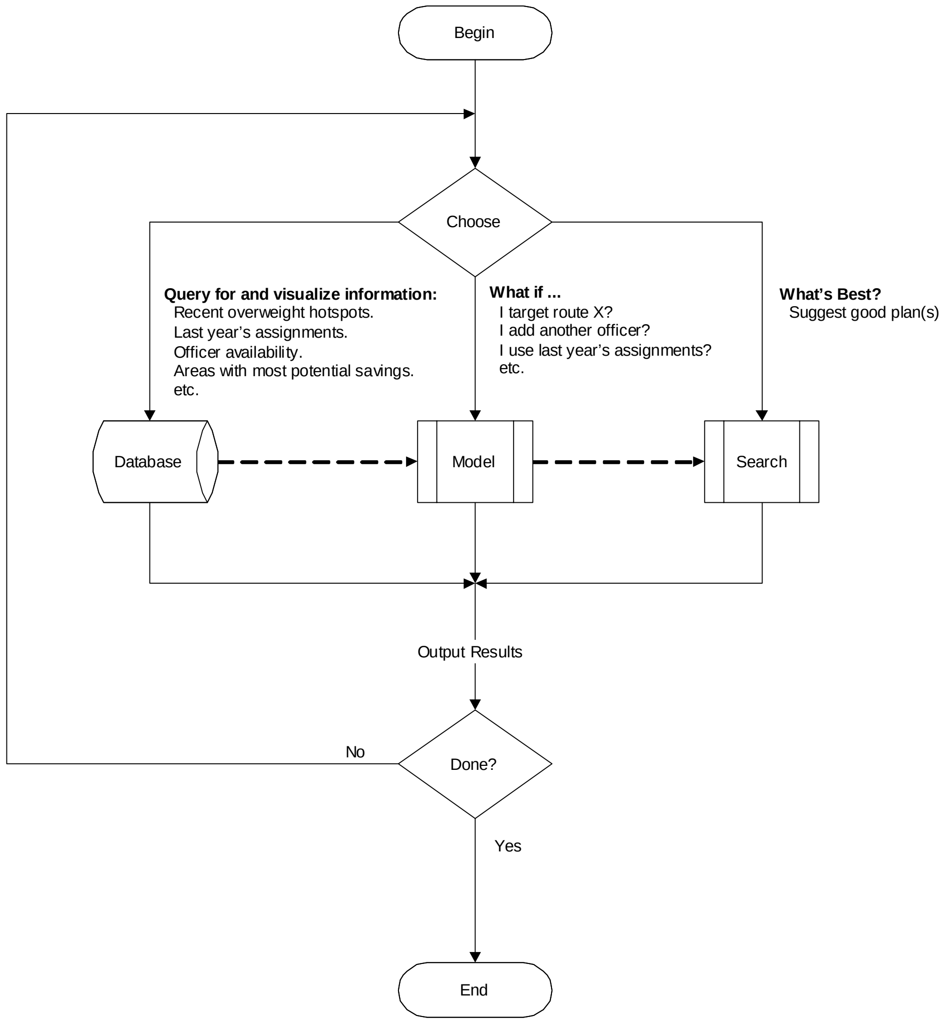


Figure 15. EPS Supported Planning Process

The EPS would support an iterative enforcement planning process as shown in Figure 15. Interactive queries and visualization would aid the user in developing alternatives. For example, questions that might be asked include: "Where are the hotspots?," "How does the current data differ from last year or the long-term average?," "What assignments were made last year?," "Who is available next week?," "What fraction of the overweight traffic in the hot areas is permitted?," etc.

In the "what if" mode, the user could quickly evaluate alternative enforcement plans. Questions might include: "What will happen if I put 1, 2, or 3 officers at a particular site?," and "How much damage could I avoid if I could deploy another officer?." Computerized models would quantify the likely outcomes for a specified course of action. The models would project pavement impacts and costs while assessing whether constraints such as manpower availability are violated by a particular plan.

In the "what's best" mode, the user would request computer-generated plans for various scenarios. The tool would combine search techniques with the prediction models to recommend officer assignments. The recommended assignments would be optimal for various metrics while maintaining feasibility with respect to officer availability and other constraints. Metrics would include cost of pavement damage, travel costs, etc. Of course, identified plans could be visualized, modified and evaluated interactively by the user.

6.3 Conceptual Design and Requirements

6.3.1 Design

As currently envisioned, the EPS will consist of four major components: (1) a database management system, (2) evaluation models, (3) code for searching for good solutions in "what's best" analyses, and (4) a graphical user interface. The implementation has been demonstrated by development of a prototype presented later in this report. Figure 16 shows how the system will interact with the MEARS system and other actors to acquire the necessary data and produce the outputs for the user. Actual enforcement assignments will be obtained from the regional offices to facilitate evaluation prior to and development of future plans. Geographical information will be obtained from MDT for producing map-based graphics and incorporating spatial considerations in the models.

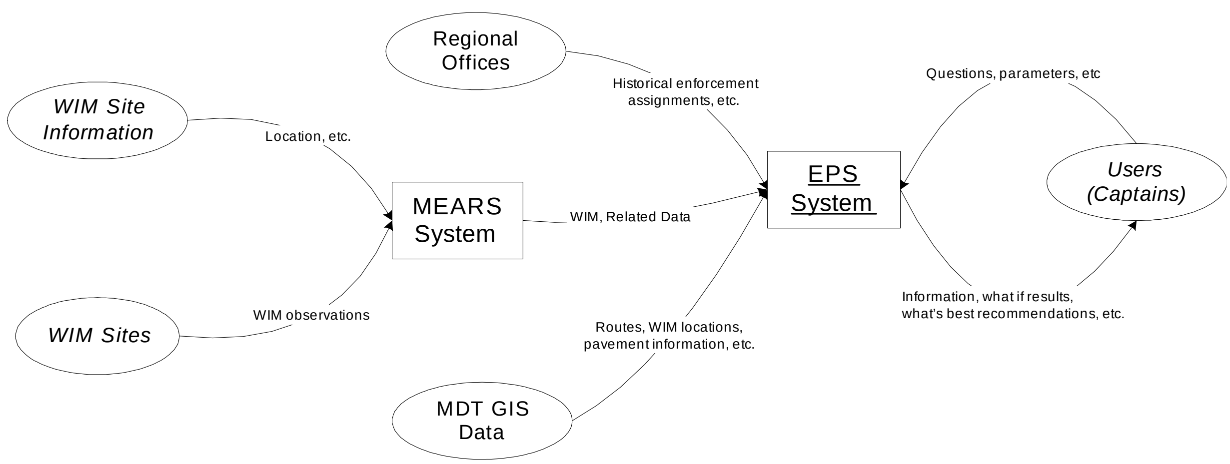


Figure 16. EPS Related Data Flow

It is assumed that MEARS will be the source for much of the data driving the models and displays in the EPS. Data downloaded from MEARS will include summarized WIM and other information for estimating impacts and projecting savings from enforcement resource allocation plans. It is possible that the enforcement assignments would be captured first by MEARS and transferred to the EPS as well. Clearly, close coordination with the MDT MEARS, GIS and other staff will be required.

6.3.2 Requirements

Given the goals, envisioned use and conceptual design articulated above, several requirements have been identified for the EPS and its database, model, and interface components. Since the EPS is intended to be interactive, an overriding requirement is that the response times should be reasonable. This requirement will influence virtually all design decisions, likely resulting in displays and models based on aggregated data and derived parameters. The EPS will also be developed to be easily adapted by other states.

Also, as observed in the previous section, effective integration with existing systems such as MEARS will be necessary to guarantee that there is only one designated repository for each data element. The EPS will primarily work with data maintained in existing systems. Resolution of issues involving existing and new data elements, such as enforcement assignments, will require close collaboration with MDT personnel.

With respect to the underlying models, there is the obvious requirement that they predict, at an acceptable level of accuracy, the likely effect of enforcement actions for a given route and time frame. The models should estimate cost savings resulting from officer assignments or plans involving multiple assignments. Models will be validated with historical and current WIM data and expert judgment.

The search algorithms developed to support the "what's best" operation mode will produce credible plans, as judged by the user. Metrics identified for output by the underlying models will be used by the search to evaluate the quality of plans during the search. Tradeoffs between the search time and solution quality will be controllable by the user.

Finally, with respect to the interface, it probably should be browser based for portability and hardware independence. The GIS data will be used to provide information graphically on a map where appropriate. Scalable Vector Graphics (SVG) technology will provide the necessary drawing speed and Extended Markup Language (XML) compatibility and portability. The interface will accommodate rapid display updates and facilitate the user's movement between the three operating modes. Usability will be evaluated by appropriate MDT personnel.

6.3.3 EPS Prototype

A prototype (http://www.ime.montana.edu/~mdt/eps) has been developed to demonstrate elements of the EPS. Interaction is provided by a map-based user interface and dynamic data is stored in a relational database. As currently implemented, displays can be selected to show map features and charts of the WIM data for selected sites. Also included is the ability to view WIM traffic distribution effects. The interface utilizes scalable vector graphics technology (SVG) and will be enhanced considerably during the EPS development.

The prototype user interface allows users to interact with a map containing routes and WIM site locations on a single screen. Figure 17 shows the prototype with the navigation tools providing the zoom and panning capability. The interface uses intuitive symbols and allows for consistent browsing through the map in the zoom out mode. Highway routes are displayed by system on different layers which can be individually switched on and off on the main map using the check boxes. The response to the user interaction is almost instantaneous.

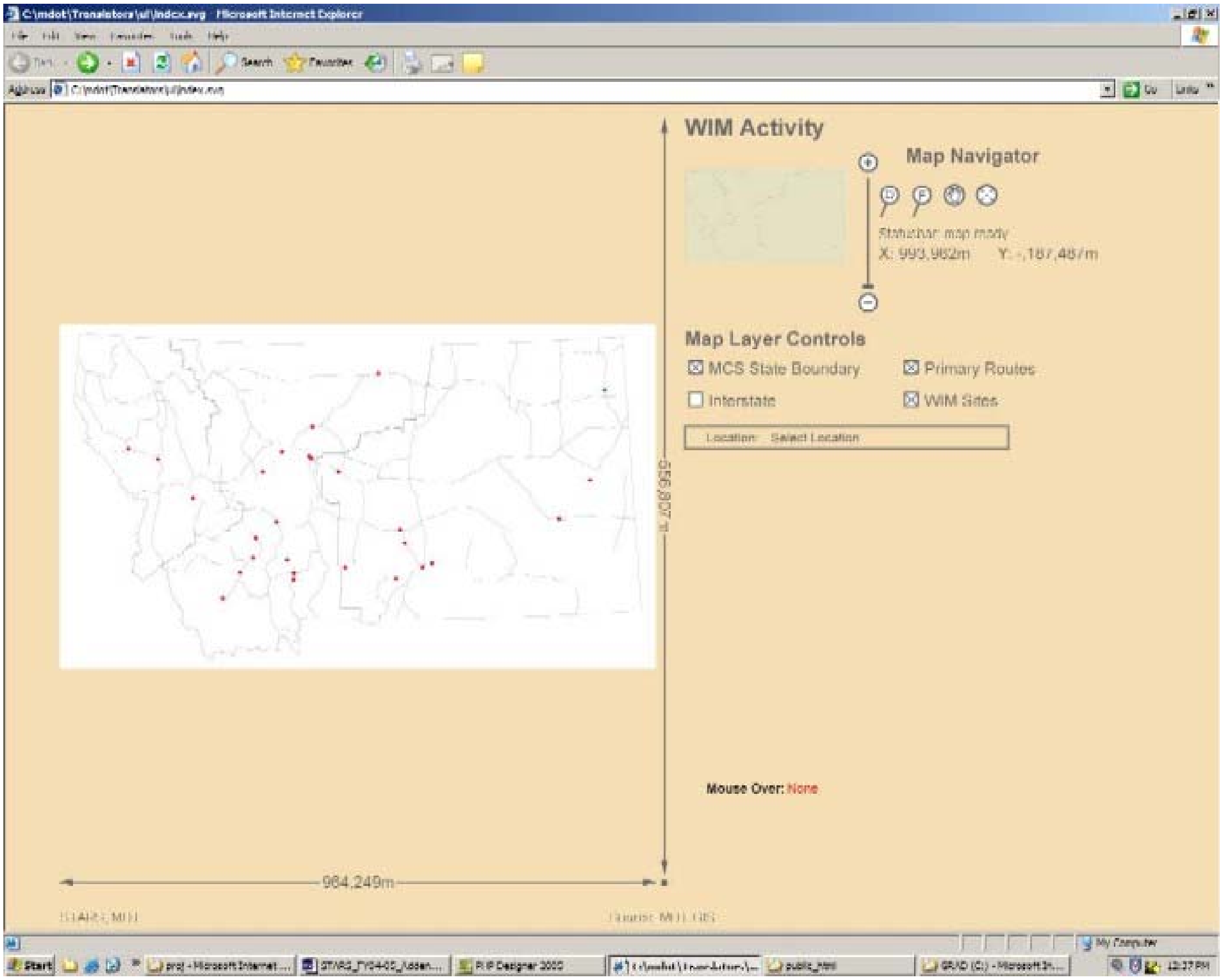


Figure 17. EPS Prototype

The prototype also displays a bar graph for the overweight vehicles for individual classes of vehicles on an hourly basis as shown in Figure 18. The underlying script for the chart display queries traffic information from the database generates the graph and displays it dynamically on the user interface. The final EPS will be able to dynamically show much more detailed statistical results graphically and numerically.

In the prototype, the STARS sites are displayed as red dots on a layer on the main map of the prototype. The sites have mouse action events associated with them. During a user session, a typical sequence of actions might be:

- the user places the mouse cursor over a STARS site.
- the site name appears in the descriptor section of the interface.
- a mouse click on the STARS site changes the color and stroke attributes of the routes/traffic operations estimated to be affected by activities at the site (see Figure 19).
- the highlighted affected routes can be restored to their original view by again clicking on the STARS site.

The WIM sites can be clicked and reset individually without affecting other WIM sites.

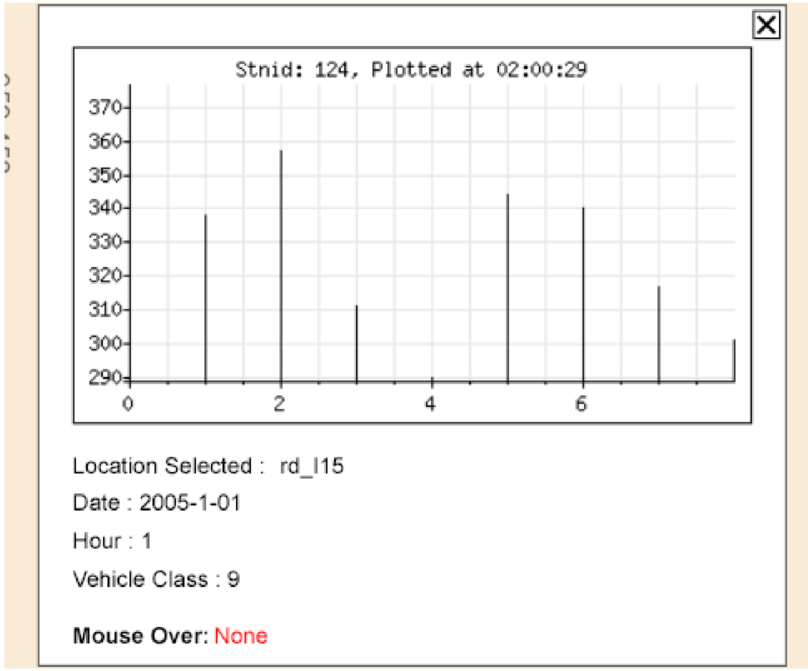


Figure 18. EPS Pop-up Graphic: Number of Overweight Vehicles as a Function of Time of Day

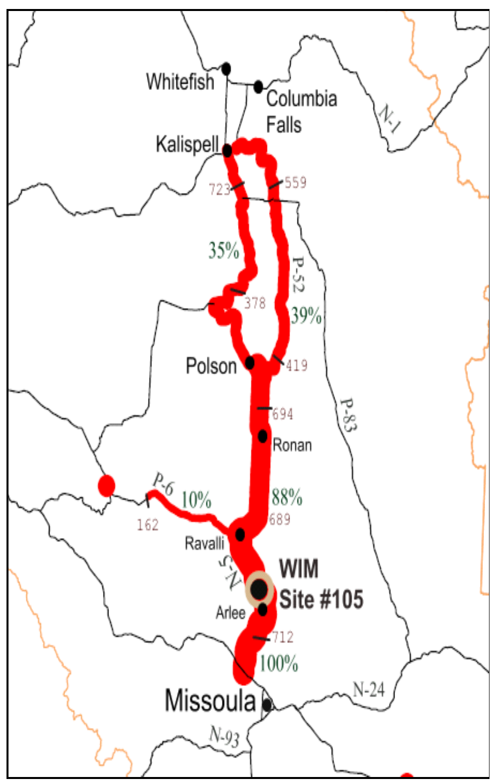


Figure 19. EPS Pop-up Graphic: Extent of System Affected by Enforcement at a Site

To create the prototype display, vector graphics render pixels from geometric shape information in the graphic file. Scalable vector graphics (SVG) is used as the open source vector graphics technology. SVG provides a zoom out capability of up to 1000% on vector shapes without any pixel distortion; this feature allows for a detailed view of the road sections and their attributes. The SVG is generated from MDT's Geographical Information System (GIS) using the open source tools available on carto.net (Cartographers on the net, 2005). The SVG conversion is performed without any loss of the route scale information; this approach retains the exact mile marker positions in the main map of the user interface.

Figure 20 shows the system diagram of the graphics generation and interaction mechanism. Preprocessing converts the relative static map display data and object attributes into SVG and relational database files from the MDT GIS shape (.shp, .dbf) files. The data can then be accessed and dynamically displayed in a web browser by php scripts. Almost all the tools used for the graphic system are open source technology.

The user interface is connected to an open source database which contains tables to store information about WIM sites, route attributes, and color scheme for affected route display. The schema used for the prototype involves the tables and information category structure that is shown Table 17. The complete schema for the prototype database is given in Appendix C. The fully functional EPS will store the entire STARS site, route attribute, and effects information in the database. Action events on user interface will invoke scripts that will query the database and display the information dynamically.

6.4 Development Plan

This section generally describes a course of action for developing an EPS that meets the requirements specified in the previous section. The major activities that must be accomplished are introduced, with associated schedule and budget information. The EPS that results from this process will effectively move the use of STARS as a tool for planning weight enforcement activities from its current prototype/experimental status to a "routine" production mode.

6.4.1 Study Activities

The general development approach will be iterative and will involve MDT Weight Enforcement personnel at each step. There are eight major tasks that must be performed to complete this study:

1. Refine requirements
2. Finalize database design
3. Populate test database(s)
4. Develop Predictive (what if) models
5. Develop "what's best" search algorithm
6. Develop map-based interactive user interface
7. Report on Project
8. Document EPS

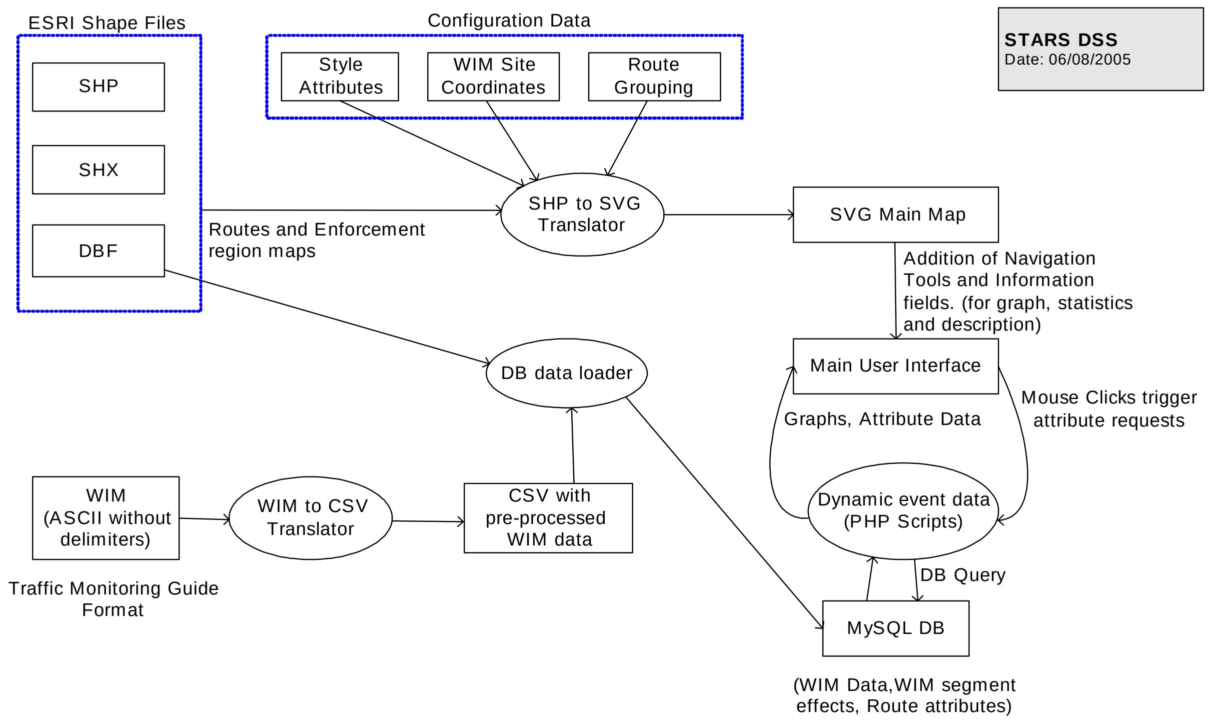


Figure 20. EPS Related Data Flow

Table 17. EPS Prototype Database Contents

Category	Table	Description
GIS data	routesegments	Holds the route segment information based on the mile markers.
WIMs data	wimsites	Holds the WIM site location id, name and mile marker information.
	wimsitesegments	Holds the information about the route traffic distribution that passes through any WIM site.
	colorSchemes	The color map for displaying the affected routes based on percentage of traffic.
	wimdata	Holds the traffic log recorded by a WIM site.
TMG Standards	weightclass	Stores the legal weight limits for each class of vehicle.
	traveldirection	The travel direction code for WIM traffic data as per the TMG (Traffic Monitoring Guide).

At the beginning of the project, MDT enforcement personnel will be interviewed to finalize the requirements for the software to insure that the end product will satisfy their needs. Use cases, describing the user view of the system will be developed and refined and will form the basis for the system design. Ideally, the completed system will complete the transition from using STARS in a prototype/research mode to using it as a full production tool to support every day enforcement resource allocation decisions.

The EPS database will integrate information from a variety of sources to drive the models and facilitate the decision process. Provision will be made to accommodate enforcement personnel assignment and pavement information. Parameters for costing pavement damage will also be incorporated in the database, along with values for other model parameters. Historical data will be needed for model development and testing. It is possible that additional data will have to be collected to fully characterize all required relationships between expenditure of enforcement effort and the attendant benefit realized. Clearly, the second and third tasks, designing and populating the EPS database, will be key to the success of the project.

Tasks four and five will result in “what if” and “what’s best” applications. The exact form of the underlying models is still to be determined, but promising alternatives include mathematical programming, simulation, and queuing network representations of the enforcement planning problem. Local search coupled with the underlying model is the most likely search technology that will be used, but other approaches will be considered as the underlying models are developed. Testing and validation will be concurrent with development and will rely heavily on MDT experts to judge the quality of the results.

Task six, developing the map-based user interface, will begin with the current prototype. The interface will be refined and tested for usability and made fully dynamic. Again, MDT personnel will be relied upon for refinement and enhancement of the interface.

Project reporting and application documentation will be accomplished by completing the last two tasks. Interim status will be reported quarterly, and documentation will be developed concurrent with application coding and testing. External publication and presentation of results will occur as results become available, and a final report on the project will be completed by the end of the study.

6.4.2 Schedule

Figure 21 shows the work breakdown structure (WBS) for the study along with the projected timeline for completion. The dark bars shown above higher level tasks in the WBS represent the total time to complete the sub-tasks shown in the WBS outline to the left. Durations were based on level-of-effort estimates presented in the next section.

6.4.3 Level of Effort and Budget

As shown in the previous section, EPS development is expected to take two years. Staffing will average two graduate students at 50% during the academic year and full time during the summers, and two faculty at 20% during the academic year (AY), and 50% in the summers. On this basis, salaries and benefits will total approximately $300,000.

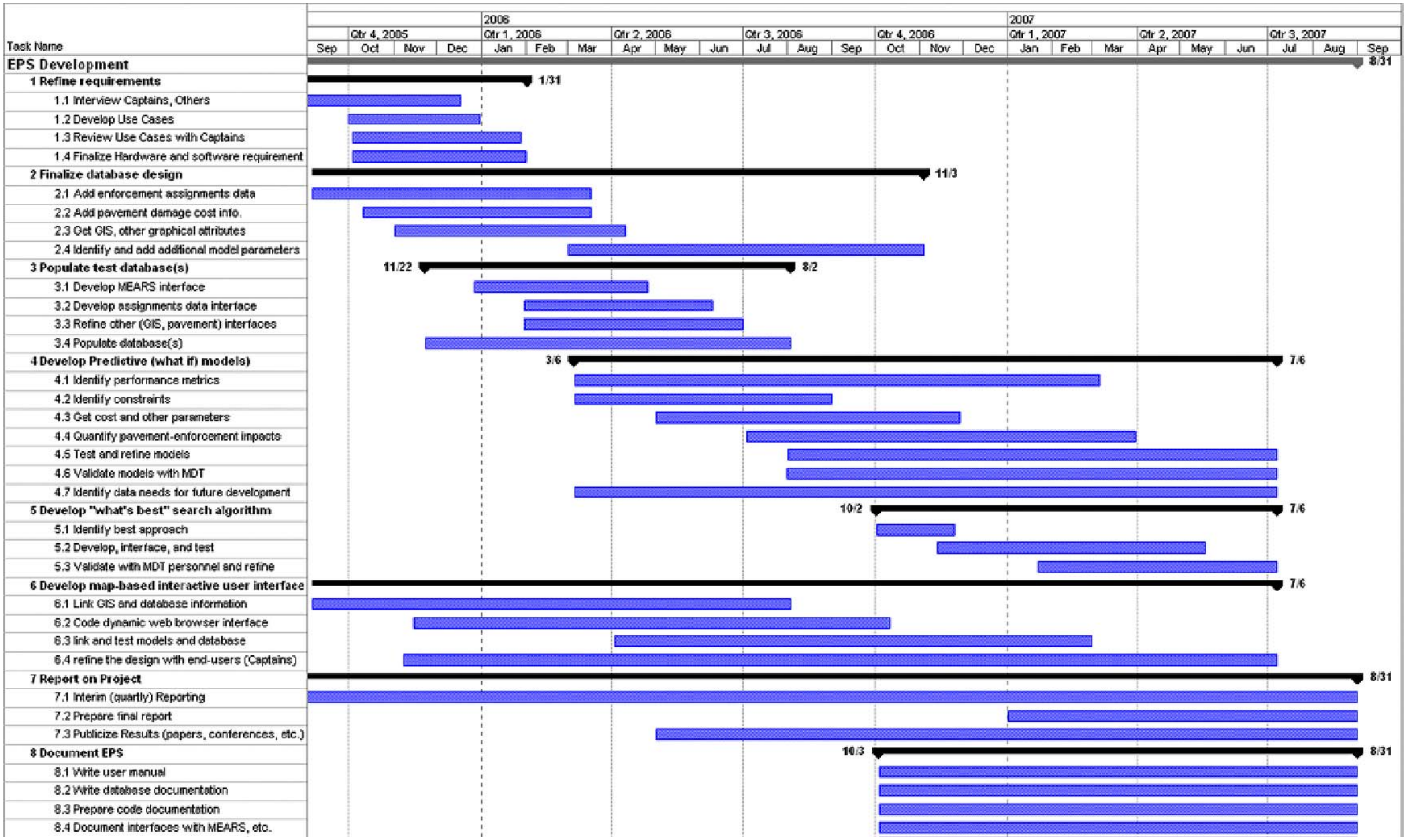


Figure 21. EPS Project Schedule

Other costs include interstate and intrastate travel ($10,000), miscellaneous supplies ($1,000) and indirect costs at 20% ($55,000). The travel estimate is based on two trips per year out of state at $2000 per trip and 10 per year in state at $100 per trip. The total estimated cost for the two year project is approximately $366,000.

7 SUMMARY AND RECOMMENDATIONS

7.1 Summary

In this project, several issues were investigated related to using STARS as a tool in the state's weight enforcement program. Specifically, work was completed on the following tasks:

1) Factors were determined to adjust the information from STARS, as processed by MEARS, to account for the presence of vehicles in the traffic stream that are compliant with state weight regulations but that are over standard weight limits. Presently, MEARS identifies as overweight any vehicle with a gross weight that exceeds a fixed limit established for a "typical" vehicle of each configuration. While this approach to identifying overweight vehicles is easy to analytically execute, it is approximate in nature, in that vehicles with a) atypical geometries, b) weights that only nominally exceed established limits, and/or c) permits that allow them to operate over standard weight limits, are classified as overweight.

   Assuming that only legally compliant vehicles operate in the presence of overt enforcement activities, factors were developed for typical STARS sites to adjust the output of MEARS for the presence of these vehicles using the "apparent" overweight vehicles identified by MEARS during known enforcement activities. Following this approach, it was found that compliant but over standard weight vehicles constituted 6.8 percent of the commercial vehicle population across the sample of 9 STARS sites considered in this analysis. This value was found to vary by vehicle configuration, location, time-of-year, and system of the highway network. Relative to vehicle configuration, for example, the greatest adjustment factors of 63, 60, and 22 percent were determined for Class 10-3, 7-2, and 7-1 vehicles, respectively. Relative to system of the highway network, average adjustment factors of 10.3, 5.1, 7.4, and 5.7 percent were calculated for the secondary, primary, and non-Interstate NHS, and Interstate systems, respectively (although the results for the secondary and primary systems are based on an analyses of data available from a single location on each system). Factors were also calculated (by configuration) to adjust for the pavement damage associated with compliant but over standard weight vehicles in the traffic stream.

   In general, the variability of the adjustment factors determined above with site location, time-of-year, and system of the highway network were large enough to encourage their development and application at as detailed a level as is possible. In this regard, much of the information required to calculate and update these factors is already collected by STARS and processed by MEARS; thus, it may be feasible to automate this process.

   With the determination of these adjustment factors, it is possible to "exactly" determine that fraction of the over standard weight vehicles at a STARS site that are operating illegally, and to then further determine the maximum benefit (that is, the cost savings in reduced pavement damage) that can be realized by totally eliminating their operation through enforcement. This information obviously is of interest in formulating enforcement resource allocation decisions. In some instances, for example, the maximum benefit to be realized may be either so small or so large that the decision whether or not to commit more enforcement resources to a site may be readily apparent. In other cases, the decision may be less clear, and use of more sophisticated decision making tools, of the kind discussed in item 4 below, may be necessary.

2) A new parameter was introduced to quantify the relative severity of the pavement damage from overweight vehicles, independent of the absolute volume of traffic under consideration. Presently, MEARS calculates pavement damage impacts in terms of the excess ESAL-miles of travel associated with overweight vehicle operations. While this parameter is critical to assigning a cost to this damage, it is sensitive to the total volume of traffic considered in the analysis. That is, for example, a large value of excess ESAL-miles of travel at a given STARS site could reflect an underlying large volume of traffic with a low incidence of overweight vehicles, or it could reflect a small amount of traffic with a high incidence of overweight vehicles. This distinction could be important in arriving at enforcement allocation decisions.

   The pavement damage parameter suggested for use is the excess ESALs associated with overweight vehicle operations divided by the total ESALs of pavement demand at a particular location. Note that this parameter will complement, rather than replace, the existing measure of pavement demand used by MEARS of excess ESAL-miles of travel. Most of the information required to calculate the new parameter is already available in MEARS. The only new variable is the total ESALs of pavement demand at a given location, which can be simply estimated as the total number of vehicles of each configuration multiplied by the average ESAL factor for that configuration (which is already calculated by MDT for pavement design purposes).

   This parameter appears to fulfill its objective of offering a “useful” indication of the relative severity of over weight vehicle impacts within a given traffic stream. At the Ryegate STARS site, for example, the fact that 17,290 excess ESALs from overweight vehicles were experienced one year is of uncertain significance when taken by itself. When this same level of overweight vehicle demand is re-stated as 13.8 percent of the total ESALs experienced at the site, the relative severity of the overweight problem at becomes somewhat more clear. The exact significance of the absolute values of this new damage parameter, as well as the significance of the quantitative changes in its value with enforcement, should become more clear over time as additional experience is gained with its calculation.

3) In using STARS information to assess the infrastructure damage associated with overweight vehicle operation, it is necessary to know not only the number of overweight vehicles that pass over a site and the amount by which they are overweight, but also the distance they travel. The former information is calculated directly by MEARS from the WIM data. The latter information on distance traveled is more difficult to determine. In calculating infrastructure impacts in the initial STARS evaluation, the traffic observed at a STARS site was assumed simply to traverse the

segment of roadway containing the STARS site itself, as defined by the first junction with a highway, Interstate or state line upstream and downstream of the site.

Naturally, many of the vehicles that pass a STARS site continue to travel on beyond the end of the road segment containing the STARS site. In the absence of origin-destination data for the vehicles traveling through each STARS site, their travel before and after they crossed a given STARS site was deduced based on a) general knowledge of the transportation corridors and type of economic activity that occurs between the population centers in the state, and b) commercial vehicle counts available along the highways in the state. The generally sparse population of the state, and often the availability of only a single major roadway connecting the population centers within the state, significantly reduced the uncertainty of these analyses. The outcome of these analyses was an "equivalent" length of the highway system associated with each STARS site that was calculated by summing the product of the length of a segment of roadway times the percent of vehicles that it carried that also passed the STARS site. In light of the somewhat subjective nature of the analysis methodology, these results need to be closely scrutinized by MDT and revised as necessary.

4) Enforcement resource allocation would be well supported by development of an *Enforcement Planning System* (EPS). The EPS would interface with existing MDT systems to support the user in making enforcement assignments to maximize effectiveness. Correlation of historical enforcement effort with reduction in pavement damage costs would form the basis of computer models that would be used for evaluating enforcement plans. These models would then use WIM and other data from MEARS to predict outcomes for assigning officers in a "what-if" mode. Coupled with search algorithms, the models could also be used to generate assignment recommendations in a "what's-best," or optimization, mode. Users would interact with the EPS through an intuitive, map-based, graphical interface. Finally, the EPS would be developed to be easily adapted by other states.

   A prototype (http://www.ime.montana.edu/~mdt/eps) was developed to demonstrate elements of the EPS. Interaction is provided by a map-based user interface and dynamic data is stored in a relational database. As currently implemented, displays can be selected to show map features and charts of the WIM data for selected sites. Also included is the ability to view WIM traffic distribution effects. The interface utilizes scalable vector graphics technology (SVG) and will be enhanced considerably during the EPS development. Full development of the EPS is estimated to take two years and will cost approximately $370,000.

All of the above tasks support the continued development of STARS as a tool for improving the effectiveness and efficiency of the state's weight enforcement efforts, with the intent of continuing to move forward from a pilot program mode of operation to a routine production mode of operation.

7.2 Recommended Future Work

Based on the body of work completed to-date, the following suggestions are made for future work:

1) Basic methodologies for determining
    a) adjustment factors for the presence of legally compliant but over standard weight vehicles in the traffic stream, and
    b) the extent of highway operations characterized by the overweight vehicle profiles identified at an individual STARS site,

    were validated in this study using information available from the 16 sites included in the initial STARS evaluation. Similar analyses should be done for the remaining 12 STARS sites. Note that in the case of the adjustment factors, while the average values determined by system in this analysis can reasonably be applied across all the STARS sites, better results will be obtained (notably, for site specific analyses) using site specific values.

2) MEARS should be modified to include calculation of a new pavement damage parameter, that is, excess ESALs as a percent of the total ESALs experienced at a location.

3) Work should proceed on developing the EPS outlined above. This new program will allow STARS/MEARS to transition from simply providing data on overweight vehicle operations, to pro-actively offering suggestions on how to allocate enforcement resources to maximize their cost effectiveness.

4) Work on one of the original tasks of this project, incorporating a STARS related component into the FHWA weight enforcement plan and certification process, could not be completed within the allocated time and resources. Nonetheless, this task definitely should be accomplished, as the information from STARS offers the ability to assess the effectiveness of weight enforcement directly in terms of one of its primary objectives, the reduction of excess infrastructure damage (in this case, excess pavement damage) from overweight vehicles.

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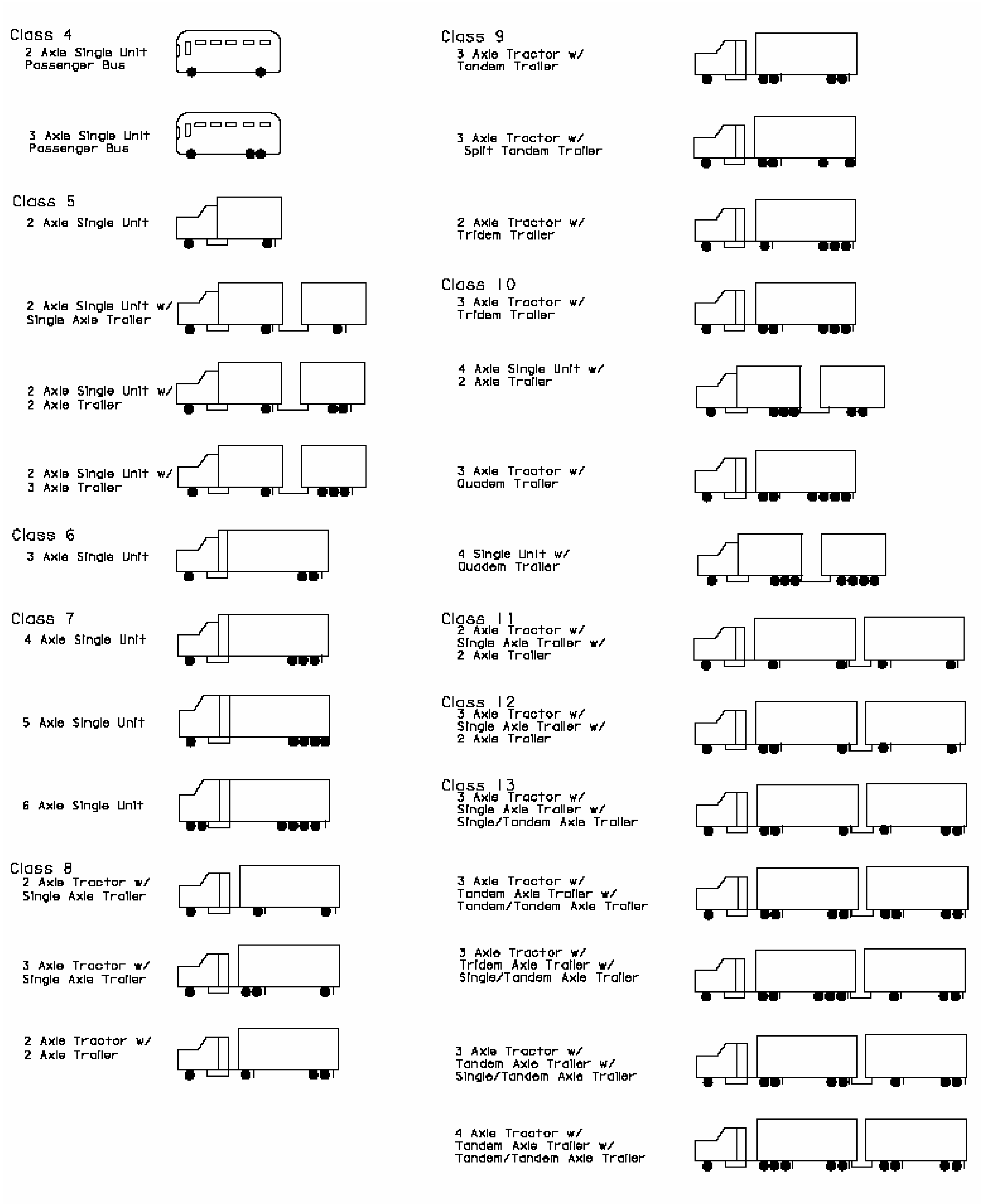
APPENDIX A
VEHICLE CLASS DESCRIPTION



Class 4
2 Axle Single Unit Passenger Bus
3 Axle Single Unit Passenger Bus
Class 5
2 Axle Single Unit
2 Axle Single Unit w/ Single Axle Trailer
2 Axle Single Unit w/ 2 Axle Trailer
2 Axle Single Unit w/ 3 Axle Trailer
Class 6
3 Axle Single Unit
Class 7
4 Axle Single Unit
5 Axle Single Unit
6 Axle Single Unit
Class 8
2 Axle Tractor w/ Single Axle Trailer
3 Axle Tractor w/ Single Axle Trailer
2 Axle Tractor w/ 2 Axle Trailer
Class 9
3 Axle Tractor w/ Tandem Trailer
3 Axle Tractor w/ Split Tandem Trailer
2 Axle Tractor w/ Tridem Trailer
Class 10
3 Axle Tractor w/ Tridem Trailer
4 Axle Single Unit w/ 2 Axle Trailer
3 Axle Tractor w/ Quadem Trailer
4 Single Unit w/ Quadem Trailer
Class 11
2 Axle Tractor w/ Single Axle Trailer w/ 2 Axle Trailer
Class 12
3 Axle Tractor w/ Single Axle Trailer w/ 2 Axle Trailer
Class 13
3 Axle Tractor w/ Single Axle Trailer w/ Single/Tandem Axle Trailer
3 Axle Tractor w/ Tandem Axle Trailer w/ Tandem/Tandem Axle Trailer
3 Axle Tractor w/ Tridem Axle Trailer w/ Single/Tandem Axle Trailer
3 Axle Tractor w/ Tandem Axle Trailer w/ Single/Tandem Axle Trailer
4 Axle Tractor w/ Tandem Axle Trailer w/ Tandem/Tandem Axle Trailer

APPENDIX B
MEARS ADJUSTMENT FACTORS

Table 1B. Adjustment Factors by Month, Decker

Vehicle Class[a]	% Compliant but Over Standard Weight Vehicles			Compliant Excess ESALS per Vehicle		
	Sep	Feb	Combined[b]	Sep	Feb	Combined[b]
4 – 1	0.0	0.0	0.0	0.000	0.000	0.000
4 – 2	23.1	33.3	25.0	0.108	0.144	0.113
5 – 1	1.1	2.4	1.9	0.042	0.032	0.047
5 – 2	0.0	0.0	0.0	0.000	0.000	0.000
5 – 3	0.0	0.0	0.0	0.000	0.000	0.000
5 – 4	0.0	0.0	0.0	0.000	0.000	0.000
6 – 1	23.3	16.2	18.8	0.242	0.424	0.344
7 – 1	0.0	66.7	20.0	0.000	0.091	0.014
7 – 2	0.0	75.0	75.0	0.000	0.664	0.332
7 – 3	0.0	0.0	0.0	0.000	0.000	0.000
8 – 1	0.0	0.0	0.0	0.000	0.000	0.000
8 – 2	0.0	0.0	0.0	0.000	0.000	0.000
9 – 1	11.1	31.7	22.9	0.079	0.491	0.258
9 – 2	8.3	15.4	12.0	0.008	0.844	0.335
9 – 3	0.0	0.0	0.0	0.000	0.000	0.000
10 – 1	12.5	20.0	18.2	0.018	0.078	0.048
10 – 2	0.0	0.0	0.0	0.000	0.000	0.000
10 – 3	0.0	0.0	0.0	0.000	0.000	0.000
11 – 1	0.0	0.0	0.0	0.000	0.000	0.000
12 – 1	0.0	0.0	0.0	0.000	0.000	0.000
13 – 1	0.0	0.0	0.0	0.000	0.000	0.000
13 – 2	7.3	2.9	5.3	0.078	0.005	0.032
13 – 3	0.0	10.0	5.6	0.000	0.099	0.028
13 – 4	8.6	15.8	11.1	0.090	0.180	0.122
All	7.6	12.7	10.33	0.072	0.208	0.134

[a] See Appendix A for a description of the vehicle classes

[b] Weighted average based on no. of vehicles

Table 2B. Adjustment Factors by Month, Miles City East

Vehicle Class[a]	% Compliant but Over Standard Weight Vehicles		Compliant Excess ESALS per Vehicle	
	Aug	Combined	Aug	Combined
4 – 1	0.0	0.0	0.000	0.000
4 – 2	0.0	0.0	0.000	0.000
5 – 1	0.0	0.0	0.000	0.000
5 – 2	0.0	0.0	0.000	0.000
5 – 3	0.0	0.0	0.000	0.000
5 – 4	0.0	0.0	0.000	0.000
6 – 1	0.0	0.0	0.000	0.000
7 – 1	0.0	0.0	0.000	0.000
7 – 2	0.0	0.0	0.000	0.000
7 – 3	0.0	0.0	0.000	0.000
8 – 1	0.0	0.0	0.000	0.000
8 – 2	0.0	0.0	0.000	0.000
9 – 1	8.8	8.8	0.017	0.017
9 – 2	0.0	0.0	0.000	0.000
9 – 3	0.0	0.0	0.000	0.000
10 – 1	12.0	12.0	0.091	0.091
10 – 2	100.0	100.0	0.390	0.390
10 – 3	100.0	100.0	0.038	0.038
11 – 1	0.0	0.0	0.000	0.000
12 – 1	0.0	0.0	0.000	0.000
13 – 1	0.0	0.0	0.000	0.000
13 – 2	0.0	0.0	0.000	0.000
13 – 3	0.0	0.0	0.000	0.000
13 – 4	0.0	0.0	0.000	0.000
All	5.1	5.1	0.016	0.016

[a] See Appendix A for a description of the vehicle classes

Table 3B. Adjustment Factors by Month, Arlee

Vehicle Class[a]	% Compliant but Over Standard Weight Vehicles			Compliant Excess ESALS per Vehicle		
	Jul	Jan	Combined[b]	Jul	Jan	Combined[b]
4 – 1	0.0	0.0	0.0	0.000	0.000	0.000
4 – 2	6.9	0.0	3.7	0.012	0.000	0.003
5 – 1	0.3	0.0	0.2	0.002	0.000	0.001
5 – 2	0.0	0.0	0.0	0.000	0.000	0.000
5 – 3	0.0	0.0	0.0	0.000	0.000	0.000
5 – 4	0.0	0.0	0.0	0.000	0.000	0.000
6 – 1	1.2	0.6	0.9	0.005	0.009	0.008
7 – 1	0.0	0.0	0.0	0.000	0.000	0.000
7 – 2	0.0	0.0	0.0	0.000	0.000	0.000
7 – 3	0.0	0.0	0.0	0.000	0.000	0.000
8 – 1	0.0	0.0	0.0	0.000	0.000	0.000
8 – 2	0.0	0.0	0.0	0.000	0.000	0.000
9 – 1	5.2	12.1	8.7	0.013	0.066	0.035
9 – 2	0.0	0.0	0.0	0.000	0.000	0.000
9 – 3	0.0	0.0	0.0	0.000	0.000	0.000
10 – 1	6.3	8.8	7.5	0.040	0.042	0.042
10 – 2	7.7	11.5	9.6	0.031	0.048	0.039
10 – 3	77.5	57.1	67.1	0.072	0.041	0.055
11 – 1	0.0	0.0	0.0	0.000	0.000	0.000
12 – 1	0.0	0.0	0.0	0.000	0.000	0.000
13 – 1	0.0	0.0	0.0	0.000	0.000	0.000
13 – 2	0.0	0.0	0.0	0.000	0.000	0.000
13 – 3	26.9	18.3	22.9	0.086	0.103	0.101
13 – 4	2.6	3.6	3.0	0.018	0.018	0.018
All	4.7	6.5	5.6	0.013	0.031	0.021

[a] See Appendix A for a description of the vehicle classes

[b] Weighted average based on no. of vehicles

Table 4B. Adjustment Factors by Month, Four Corners/Gallatin

Vehicle Class[a]	% Compliant but Over Standard Weight Vehicles					Compliant Excess ESALS per Vehicle				
	Jul	Sep	Dec	Mar	Combined[b]	Jul	Sep	Dec	Mar	Combined[b]
4 – 1	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
4 – 2	3.6	5.9	0.0	0.0	3.4	0.004	0.036	0.000	0.000	0.002
5 – 1	2.0	0.0	0.0	2.9	1.4	0.106	0.000	0.000	0.022	0.005
5 – 2	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
5 – 3	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
5 – 4	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
6 – 1	5.4	5.7	10.7	0.0	5.7	0.030	0.047	0.074	0.000	0.036
7 – 1	20.0	0.0	0.0	100.0	21.1	0.091	0.000	0.000	0.442	0.046
7 – 2	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
7 – 3	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
8 – 1	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
8 – 2	2.6	0.0	0.0	0.0	1.2	0.009	0.000	0.000	0.000	0.004
9 – 1	9.3	11.5	15.2	19.0	13.2	0.073	0.049	0.084	0.162	0.088
9 – 2	3.6	1.2	10.2	12.8	6.4	0.043	0.003	0.082	0.247	0.064
9 – 3	0.0	100.0	0.0	0.0	50.0	0.000	1.840	0.000	0.000	0.920
10 – 1	14.6	3.8	17.6	17.6	12.5	0.150	0.008	0.108	0.074	0.064
10 – 2	0.0	10.0	0.0	0.0	3.6	0.000	0.017	0.000	0.000	0.006
10 – 3	100.0	25.0	100.0	0.0	50.0	0.101	0.003	0.108	0.000	0.028
11 – 1	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
12 – 1	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
13 – 1	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
13 – 2	4.0	0.0	2.4	1.3	2.0	0.017	0.000	0.034	0.042	0.019
13 – 3	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
13 – 4	0.0	25.0	0.0	0.0	2.9	0.000	0.065	0.000	0.000	0.007
All	6.2	6.0	10.1	12.9	8.0	0.061	0.028	0.062	0.128	0.064

[a] See Appendix A for a description of the vehicle classes

[b] Weighted average based on no. of vehicles

Table 5B. Adjustment Factors by Month, Townsend

Vehicle Class[a]	% Compliant but Over Standard Weight Vehicles				Compliant Excess ESALS per Vehicle			
	Jun	Sep	Dec	Combined[b]	Jun	Sep	Dec	Combined[b]
4 – 1	5.6	0.0	0.0	1.6	0.032	0.000	0.000	0.009
4 – 2	20.0	0.0	11.1	10.3	0.148	0.000	0.020	0.019
5 – 1	1.0	0.0	0.0	0.6	0.006	0.000	0.000	0.004
5 – 2	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
5 – 3	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
5 – 4	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
6 – 1	3.6	3.5	4.3	3.9	0.018	0.041	0.096	0.046
7 – 1	50.0	0.0	0.0	33.3	0.764	0.000	0.000	0.509
7 – 2	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
7 – 3	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
8 – 1	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
8 – 2	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
9 – 1	15.6	11.7	12.5	13.2	0.190	0.073	0.098	0.104
9 – 2	3.6	0.0	3.6	2.9	0.039	0.000	0.067	0.031
9 – 3	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
10 – 1	4.5	5.8	13.8	7.8	0.063	0.031	0.113	0.064
10 – 2	0.0	0.0	40.0	15.4	0.000	0.000	0.317	0.122
10 – 3	50.0	60.0	72.7	63.6	0.152	0.047	0.067	0.059
11 – 1	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
12 – 1	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
13 – 1	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
13 – 2	8.1	0.0	3.2	3.3	0.044	0.000	0.063	0.018
13 – 3	3.8	7.7	28.0	13.0	0.043	0.006	0.123	0.057
13 – 4	8.0	0.0	4.7	4.7	0.069	0.000	0.020	0.020
All	6.9	5.8	7.9	7.0	0.072	0.034	0.065	0.058

[a] See Appendix A for a description of the vehicle classes

[b] Weighted average based on no. of vehicles

Table 6B. Adjustment Factors by Month, Ryegate

Vehicle Class[a]	% Compliant but Over Standard Weight Vehicles				Compliant Excess ESALS per Vehicle			
	Nov	Jan	Mar	Combined[b]	Nov	Jan	Mar	Combined[b]
4 – 1	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
4 – 2	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
5 – 1	10.3	0.0	3.0	4.3	0.063	0.000	0.012	0.016
5 – 2	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
5 – 3	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
5 – 4	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
6 – 1	3.7	0.0	9.1	3.7	0.148	0.000	0.066	0.027
7 – 1	0.0	100.0	0.0	100.0	0.000	0.368	0.000	0.368
7 – 2	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
7 – 3	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
8 – 1	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
8 – 2	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
9 – 1	9.1	16.0	3.5	10.0	0.026	0.090	0.011	0.031
9 – 2	2.1	11.8	0.0	4.7	0.026	0.228	0.000	0.058
9 – 3	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
10 – 1	18.1	12.9	6.7	15.5	0.040	0.070	0.025	0.059
10 – 2	23.1	100.0	0.0	26.7	0.027	0.110	0.000	0.029
10 – 3	65.1	50.0	100.0	65.2	0.024	0.028	0.174	0.036
11 – 1	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
12 – 1	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
13 – 1	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000
13 – 2	0.0	3.8	0.0	0.6	0.000	0.017	0.000	0.003
13 – 3	7.7	5.6	0.0	4.0	0.012	0.007	0.000	0.005
13 – 4	5.7	3.7	3.1	4.3	0.011	0.020	0.004	0.008
All	11.2	12.1	3.1	9.5	0.027	0.073	0.010	0.031

[a] See Appendix A for a description of the vehicle classes

[b] Weighted average based on no. of vehicles

Table 7B. Adjustment Factors by Month, Stanford

Vehicle Class[a]	% Compliant but Over Standard Weight Vehicles					Compliant Excess ESALS per Vehicle				
	Jun	Sep	Nov	Feb	Combined[b]	Jun	Sep	Nov	Feb	Combined[b]
4 – 1	0.0	15.4	20.0	0.0	10.2	0.000	0.075	0.345	0.000	0.025
4 – 2	0.0	0.0	12.5	12.5	7.7	0.000	0.000	0.063	0.044	0.013
5 – 1	1.7	1.9	0.0	1.7	1.0	0.185	0.023	0.000	0.002	0.007
5 – 2	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
5 – 3	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
5 – 4	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
6 – 1	9.8	6.3	6.4	10.0	8.2	0.023	0.362	0.055	0.061	0.060
7 – 1	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
7 – 2	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
7 – 3	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
8 – 1	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
8 – 2	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
9 – 1	14.6	14.6	10.9	12.2	12.9	0.077	0.071	0.073	0.075	0.074
9 – 2	4.8	6.2	8.1	4.1	6.1	0.243	0.083	0.133	0.009	0.090
9 – 3	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
10 – 1	12.3	13.2	5.9	17.2	10.2	0.083	0.086	0.023	0.080	0.057
10 – 2	0.0	33.3	0.0	50.0	10.5	0.000	0.018	0.000	0.108	0.003
10 – 3	100.0	0.0	42.3	0.0	43.8	0.120	0.000	0.016	0.000	0.008
11 – 1	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
12 – 1	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
13 – 1	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
13 – 2	0.0	0.0	0.0	2.0	0.2	0.000	0.000	0.000	0.007	0.001
13 – 3	0.0	0.0	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000
13 – 4	2.8	0.0	1.8	4.5	2.4	0.028	0.000	0.030	0.009	0.015
All	8.1	9.2	7.1	8.9	8.10	0.063	0.058	0.049	0.049	0.054

[a] See Appendix A for a description of the vehicle classes
[b] Weighted average based on no. of vehicles

Table 8B. Adjustment Factors by Month, Manhattan

Vehicle Class[a]	% Compliant but Over Standard Weight Vehicles			Compliant Excess ESALS per Vehicle		
	Oct	Jan	Combined[b]	Oct	Jan	Combined[b]
4 – 1	0.0	0.0	0.0	0.000	0.000	0.000
4 – 2	13.6	7.7	11.4	0.087	0.015	0.048
5 – 1	0.5	0.0	0.3	0.004	0.000	0.001
5 – 2	0.0	0.0	0.0	0.000	0.000	0.000
5 – 3	0.0	0.0	0.0	0.000	0.000	0.000
5 – 4	0.0	0.0	0.0	0.000	0.000	0.000
6 – 1	9.7	9.0	9.4	0.083	0.100	0.092
7 – 1	37.5	0.0	21.4	0.213	0.000	0.061
7 – 2	0.0	0.0	0.0	0.000	0.000	0.000
7 – 3	0.0	0.0	0.0	0.000	0.000	0.000
8 – 1	0.0	0.0	0.0	0.000	0.000	0.000
8 – 2	0.0	1.3	0.7	0.000	0.003	0.001
9 – 1	8.6	7.9	8.2	0.028	0.037	0.033
9 – 2	3.5	2.0	2.7	0.026	0.010	0.017
9 – 3	0.0	0.0	0.0	0.000	0.000	0.000
10 – 1	15.1	7.4	11.9	0.067	0.089	0.098
10 – 2	3.3	0.0	1.8	0.004	0.000	0.001
10 – 3	68.2	72.2	70.0	0.053	0.041	0.047
11 – 1	0.0	0.0	0.0	0.000	0.000	0.000
12 – 1	0.0	0.0	0.0	0.000	0.000	0.000
13 – 1	0.0	0.0	0.0	0.000	0.000	0.000
13 – 2	1.7	0.4	1.0	0.023	0.001	0.008
13 – 3	2.4	2.0	2.2	0.006	0.006	0.006
13 – 4	2.2	3.7	3.0	0.011	0.015	0.014
All	6.4	5.5	6.0	0.026	0.028	0.028

[a] See Appendix A for a description of the vehicle classes

[b] Weighted average based on no. of vehicles

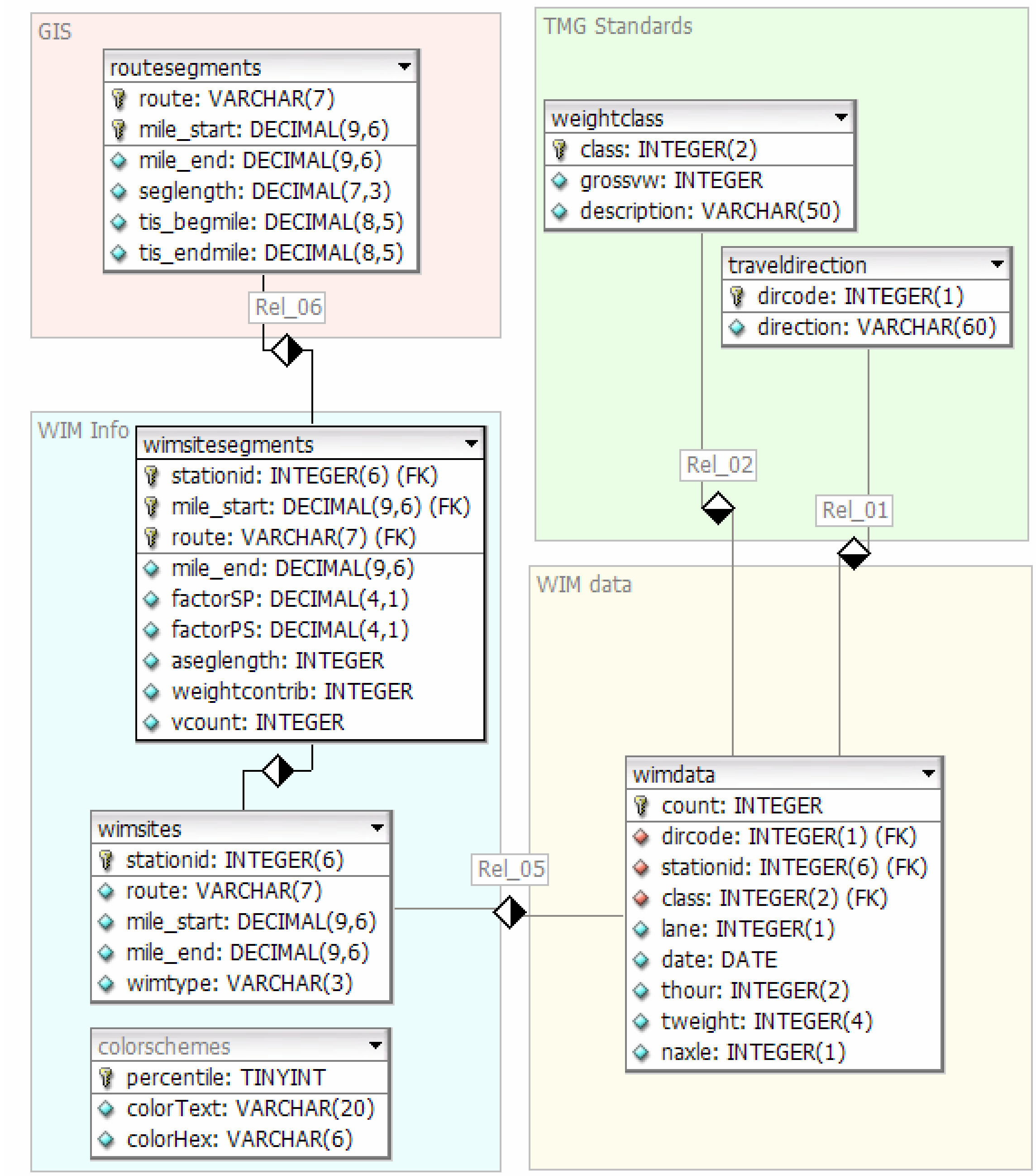
Table 9B. Adjustment Factors by Month, Ulm

Vehicle Class[a]	% Compliant but Over Standard Weight Vehicles			Compliant Excess ESALS per Vehicle		
	Nov	Feb	Combined[b]	Nov	Feb	Combined[b]
4 – 1	0.0	0.0	0.0	0.000	0.000	0.000
4 – 2	7.7	13.3	10.7	0.065	0.087	0.080
5 – 1	0.0	0.0	0.0	0.000	0.000	0.000
5 – 2	0.0	0.0	0.0	0.000	0.000	0.000
5 – 3	0.0	0.0	0.0	0.000	0.000	0.000
5 – 4	0.0	0.0	0.0	0.000	0.000	0.000
6 – 1	14.8	4.8	12.0	0.297	0.060	0.196
7 – 1	50.0	0.0	50.0	0.269	0.000	0.134
7 – 2	0.0	0.0	0.0	0.000	0.000	0.000
7 – 3	0.0	0.0	0.0	0.000	0.000	0.000
8 – 1	0.0	0.0	0.0	0.000	0.000	0.000
8 – 2	0.0	10.0	2.4	0.000	0.007	0.001
9 – 1	4.1	9.2	6.2	0.022	0.056	0.035
9 – 2	1.9	0.0	0.9	0.059	0.000	0.014
9 – 3	0.0	0.0	0.0	0.000	0.000	0.000
10 – 1	8.9	0.9	5.7	0.030	0.000	0.011
10 – 2	11.1	0.0	7.1	0.011	0.000	0.004
10 – 3	41.7	100.0	56.3	0.031	0.088	0.046
11 – 1	0.0	0.0	0.0	0.000	0.000	0.000
12 – 1	0.0	0.0	0.0	0.000	0.000	0.000
13 – 1	0.0	0.0	0.0	0.000	0.000	0.000
13 – 2	0.6	0.0	0.5	0.003	0.000	0.001
13 – 3	0.0	0.0	0.0	0.000	0.000	0.000
13 – 4	1.1	0.0	0.8	0.023	0.000	0.008
All	4.1	5.7	4.7	0.028	0.032	0.029

[a] See Appendix A for a description of the vehicle classes
[b] Weighted average based on no. of vehicles

APPENDIX C
EPS PROTOTYPE DATABASE DETAILS

C.1 Database Schema



C.2 Database Table Information

C.2.1 GIS Data

routesegments - Holds route and its component (segment) information.

Column Name	Data Type	Primary Key	Not Null	Comment
route	VARCHAR(7)	PK	NN	Route String
mile_start	DECIMAL(9,6)	PK	NN	Mile Start
mile_end	DECIMAL(9,6)		NN	Mile End
seglength	DECIMAL(7,3)		NN	Segment Length
Tis_begmile	DECIMAL(8,5)			
Tis_endmile	DECIMAL(8,5)			

Note: Needs addition of some fields based on header information in DBF files.

C.2.2 TMG (Traffic Monitoring Guide) Standards

weightclass - Holds the legal weight limits for Truck load

Column Name	Data Type	Primary Key	Not Null	Flags	Comment
Class	INTEGER(2)	PK	NN	UNSIGNED	Vehicle Class (as per TMG)
grossvw	INTEGER		NN	UNSIGNED	Gross Vehicle Weight in Pounds
description	VARCHAR(50)				Class Descriptor

traveldirection - Holds direction of travel information based on codes specified in TMG

Column Name	Data Type	Primary Key	Not Null	Flags	Comment
dircode	INTEGER(1)	PK	NN	UNSIGNED	Direction Code (as per TMG)
direction	VARCHAR(60)		NN		Direction of Travel (as per TMG)

C2.1.3 WIM Data

wimdata - Table for charts. Used by PHP application to plot the overweight data.

Column Name	Data Type	Primary Key	Not Null	Flags	Comment	Auto Inc
Count	INTEGER	PK	NN	UNSIGNED	Record Index	AI
dircode	INTEGER(1)		NN	UNSIGNED	Direction of Travel Code	
stationid	INTEGER(6)			UNSIGNED	Station ID	
Class	INTEGER(2)		NN	UNSIGNED	Vehicle Class	
Lane	INTEGER(1)			UNSIGNED	Lane of Travel	
Date	DATE		NN		Date of Data	
Thour	INTEGER(2)		NN	UNSIGNED	Hour of Data	
tweight	INTEGER(4)		NN	UNSIGNED	Total Weight of Vehicle	
Naxle	INTEGER(1)			UNSIGNED	Number of Axles	

colorschemes - Color map to show WIMS traffic distribution across different routes

Column Name	Data Type	Primary Key	Not Null	Flags
percentile	TINYINT	PK	NN	UNSIGNED
colorText	VARCHAR(20)			
colorHex	VARCHAR(6)			