

An evaluation of Montanas state truck activities reporting system (stars)
by Danielle Marie Reagor

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering
Montana State University
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Abstract:
Since the introduction of weigh-in-motion (WIM) and automatic vehicle classification (AVC) technologies, the collection of commercial vehicle operations data has been greatly enhanced. WIM/AVC information can be used to achieve long-term infrastructure preservation by supporting overweight enforcement efforts. With this application in mind, the Montana Department of Transportation (MDT) has recently completed a pilot project referred to as the State Truck Activities Reporting System or STARS.

This program consists of a series of WIM/AVC systems deployed across the Montana highway system. The objectives of the program are to improve the efficiency of MDT's commercial vehicle enforcement program and to improve the quality and quantity of truck weight and classification data. One year of historical data was used to establish a baseline of overweight commercial vehicle activity. In the following year, mobile enforcement efforts were dispatched based on the WIM/AVC data collected from the STARS sites the previous year.

The findings of this investigation suggest that the program has been a success. Generally, a reduction in the proportion of overweight vehicles during months of STARS focused enforcement was observed. The findings also show that pavement damage (ESALs) was effectively reduced when this method for scheduling enforcement activities was used. The overall reduction in pavement damage attributable to the STARS program statewide in 2001-2002 was on the order of magnitude of 10 million ESAL-miles of travel. The cost savings associated with this change in pavement damage was approximately $1 million.

This program would possibly provide greater benefits if an increased number of years of historical data were available on which to base focused enforcement efforts. Another issue to consider is whether or not the same techniques used in this pilot project to select enforcement sites can be used in the future. The effects of this program may in fact decrease future effectiveness as the motor carrier industry adjusts their loading behavior. With this in mind, the MCS Division of MDT is committed to continuing to investigate techniques to improve their effectiveness and strongly believe that WIM will continue to have a role in their future enforcement activities.

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MONTANA STATE UNIVERSITY – BOZEMAN
Bozeman, Montana

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Since the introduction of weigh-in-motion (WIM) and automatic vehicle classification (AVC) technologies, the collection of commercial vehicle operations data has been greatly enhanced. WIM/AVC information can be used to achieve long-term infrastructure preservation by supporting overweight enforcement efforts. With this application in mind, the Montana Department of Transportation (MDT) has recently completed a pilot project referred to as the *State Truck Activities Reporting System* or *STARS*.

This program consists of a series of WIM/AVC systems deployed across the Montana highway system. The objectives of the program are to improve the efficiency of MDT's commercial vehicle enforcement program and to improve the quality and quantity of truck weight and classification data. One year of historical data was used to establish a baseline of overweight commercial vehicle activity. In the following year, mobile enforcement efforts were dispatched based on the WIM/AVC data collected from the STARS sites the previous year.

The findings of this investigation suggest that the program has been a success. Generally, a reduction in the proportion of overweight vehicles during months of STARS focused enforcement was observed. The findings also show that pavement damage (ESALs) was effectively reduced when this method for scheduling enforcement activities was used. The overall reduction in pavement damage attributable to the STARS program statewide in 2001-2002 was on the order of magnitude of 10 million ESAL-miles of travel. The cost savings associated with this change in pavement damage was approximately $1 million.

This program would possibly provide greater benefits if an increased number of years of historical data were available on which to base focused enforcement efforts. Another issue to consider is whether or not the same techniques used in this pilot project to select enforcement sites can be used in the future. The effects of this program may in fact decrease future effectiveness as the motor carrier industry adjusts their loading behavior. With this in mind, the MCS Division of MDT is committed to continuing to investigate techniques to improve their effectiveness and strongly believe that WIM will continue to have a role in their future enforcement activities.

CHAPTER 1

INTRODUCTION

Since the introduction of weigh-in-motion (WIM) and automatic vehicle classification (AVC) technologies, the collection of commercial vehicle operations data has been greatly enhanced. Most commonly, the information available from WIM/AVC has been used to prescreen overweight commercial vehicles to optimize static weigh station efficiency and to support the calculation of traffic loading demands for roadway design. Beyond these common applications, WIM/AVC information can be used to achieve long-term infrastructure preservation by supporting commercial vehicle weight enforcement efforts. With this application in mind, the Montana Department of Transportation (MDT) has recently completed a pilot project referred to as the *State Truck Activities Reporting System* or *STARS*.

In cooperation with Montana State University (MSU), the impact of STARS on various MDT activities is being comprehensively evaluated. STARS consists of a series of WIM/AVC systems deployed across the Montana highway system that feed data to customized software programs. The software can subsequently be used to characterize commercial vehicle operations by classification and weight, and to further perform extensive analyses specifically addressing overweight commercial vehicle operations.

Background

The Motor Carrier Services (MCS) Division of the Montana Department of Transportation (MDT) is the entity responsible for truck size and weight enforcement in Montana. MCS currently operates a network of 21 permanent weigh stations equipped with static scales and maintains a staff of 18 mobile enforcement officers who work out of their vehicles using portable weighing equipment. Montana's weigh stations generally provide an effective enforcement presence on the routes where they are located (primarily Interstate and strategic non-Interstate highways) and at the times that they are open (24 hours a-day on busy routes and fewer hours on routes with less traffic).

MCS mobile officers currently spend most of their time (approximately 70 percent) patrolling local roads and highways that are not serviced by weigh stations. Currently, each Patrol Officer, within his or her assigned geographic area, exercises considerable discretion when deciding which roads to travel and how to be most productive. Hence the officers' effectiveness in capturing illegally overweight trucks is based on their experience, knowledge of truck traffic patterns, enforcement intuition and follow-up on public "tips" or complaints. Because a mobile officer's effectiveness is based largely on experience, new officers or staffing changes cause temporary inefficiencies in Montana's weight enforcement program. A new Patrol Officer experiences a significant learning curve while developing his or her skills, and Patrol Officers may inadvertently devote considerable time and energy to non-productive pursuits. These inefficiencies could easily be negated if pertinent information was available on chronically overweight vehicle operations.

Previously, the effectiveness of Montana's truck weight enforcement program has been evaluated using the Federal Highway Administration's (FHWA) PLAN/CERT process, in compliance with the Code of Federal Regulations (CFR) 23, Part 657. MCS prepares the Federal Truck Size and Weight Enforcement Plan (PLAN) and the Federal Certification of Accomplishment (CERT). At the beginning of the reporting period, the PLAN establishes Montana's numerical commercial vehicle enforcement goals. At the end of the reporting period, the CERT documents Montana's success in achieving the numerical goals stated in the PLAN. FHWA then judges Montana's commercial vehicle enforcement program on whether the actual numbers in the CERT meet or exceed the projected numbers in the PLAN. Although this PLAN/CERT approach standardizes the reporting process, it's utility for objectively judging state enforcement program performance and comparing the effectiveness of one state program with another state program has been questioned. This pilot project provides FHWA with the documentation and the opportunity to evaluate and consider STARS as a performance-based alternative to the Federal PLAN/CERT process.

With respect to road design, MDT's Data and Statistics Bureau currently collects and processes truck weight and classification data at 11 WIM/AVC sites across the state. This data is then used to support Equivalent Single Axle Load (ESAL) projections for pavement preservation and construction projects, support engineering decisions at the project level for long range planning, and to meet FHWA Traffic Monitoring Guide (TMG) and Strategic Highway Research Program (SHRP) requirements.

Objectives

The STARS program has two primary objectives. The first is to improve the efficiency of MDT's commercial vehicle enforcement program and to document this improvement through a noted reduction in the number of overweight trucks and the average size of the overweight load. The second is to improve the quality and quantity of truck weight and classification data available for use by MDT and to provide a means to effectively and efficiently utilize this data to achieve long-term infrastructure preservation.

The STARS program was also developed with two secondary objectives in mind. The first is to provide FHWA with both the documentation and the opportunity to consider STARS as an alternative to the Federal Truck Size and Weight Plan (PLAN) and Certification of Accomplishment (CERT) process, in which all states are currently required to participate. Second, STARS will support Montana's long-term Commercial Vehicle Operations (CVO) goals of automating the states priority weigh stations and the objectives of both the national Long Term Pavement Performance (LTPP) of the Strategic Highway Research Program (SHRP) and the Commercial Vehicle Information Systems and Networks (CVISN) initiative.

Scope

The scope of this project incorporates two full years of data collection. One year of historical data (May 2000 through April 2001) was used to establish a baseline of

overweight commercial vehicle activity at each of 16 STARS sites located across the state. In the following year (May 2001 through April 2002), mobile enforcement efforts across the state were dispatched based on the WIM/AVC data collected from the STARS sites the previous year. Naturally, it would have been preferable to have several years of historical data to more reliably characterize overweight vehicle activity prior to implementing the WIM/AVC-based enforcement, but there was considerable interest in taking advantage of STARS data as soon as possible after its deployment (which was substantially completed by May 2000) for MDT's enforcement and other activities.

CHAPTER 2

LITERATURE REVIEW

Since the advent of WIM/AVC technologies, their application and performance has been extensively studied. This Chapter details the findings of related literature categorized by: (1) use of WIM/AVC systems in enforcement, including pavement preservation and (2) use of these systems in engineering and planning efforts.

Enforcement

Several studies have been conducted that consider efforts to improve the effectiveness and efficiency of truck weight enforcement programs and the feasibility of using WIM/AVC technologies to aid in these efforts. These studies consider various aspects of enforcement, including appropriate measures of effectiveness for monitoring changes in enforcement activities, weigh station bypass operations, weigh station avoidance and mobile enforcement activities.

Measures of Effectiveness

Hanscom and Goelzer (1998) comprehensively defined measures of effectiveness (MOEs) for truck weight enforcement. Traditionally applied measures (i.e., number of trucks weighed and citations issued) have failed to provide results in terms of real enforcement objectives, such as deterring overweight trucks and minimizing pavement damage. Hanscom and Goelzer developed and subsequently validated alternate MOEs in

a comprehensive four-state field evaluation. Matched WIM/AVC data sets, collected under controlled baseline and enforcement conditions, were analyzed and the following MOEs were validated on the basis of their demonstrated sensitivity to truck weight enforcement objectives and the presence of enforcement activity: (1) severity of overweight violations, (2) proportion of overweight trucks, (3) average equivalent single-axle loads (ESALs), (4) excess ESALs and (5) bridge formula violations. These measures were proven sensitive to both legal load-limit compliance objectives of truck weight enforcement procedures and the potential for pavement deterioration.

Weigh Station Bypass Operations

Several studies have considered the application and performance of WIM/AVC for weigh station bypass operations; under such operations, trucks that are weight and credential compliant could be identified as such (in part, by WIM) and permitted to bypass the weigh station without stopping.

A study conducted by Bergan, et al. (1998) demonstrated the importance of WIM scale calibration for successful weigh station bypass operations. Statistical analyses revealed that calibrating a WIM scale to read 5 percent light decreased the probability of a legally loaded truck being recognized as overweight and being called into a weigh station, from 50 percent to anywhere between 31 and .04 percent, depending on the type of WIM scale utilized. The report concluded that the use of use of WIM/AVC technology as a pre-sorting device would dramatically improve enforcement efficiency in that delays experienced by trucks of legal weight would significantly decrease, while the probability of identifying and citing overweight trucks would increase.

Looking in more detail at the use of WIM/AVC for legal weigh station bypass operations, Chou and Tsai (1999) derived relationships that allow for the determination of appropriate overload thresholds for bypass operations given the maximum allowable reduction in pavement service life and the maximum allowable rate of misjudged overloading. The rate of correct inspection and the required WIM accuracy can also be obtained through these derived relationships.

Weigh Station Avoidance

Jessup and Casavant (1996) conversely considered the problem of illegal bypass operations around weigh stations (i.e., avoidance). The authors utilized a WIM scale in proximity to a static scale to quantify differences in time of day/day of week violation and capture rates of large trucks. Conclusions drawn were that (1) overweight and avoidance activity by the trucking industry is heavily driven by business forces, (2) an increase in the proportion of long distance trucks in the traffic stream corresponds to an increase in the average gross vehicle weight (GVW) and axle weight, (3) short distance trucks are generally the trucks that are overweight and (4) an understanding of the influence of business and economic activities on truck traffic flows is important in overweight enforcement strategies and in choosing optimal hours of weigh station operation.

Similarly, Cunagin, et al. (1997) considered the problem of weigh station avoidance for the Florida Department of Transportation (FDOT). The objective of this study was to assess the magnitude of weigh station avoidance by overweight trucks expressed in ESALs. Results of the study indicated that with increased enforcement activity, the

number of overweight vehicles decreased. However, this reduction may be attributable to the illegal bypass of overweight vehicles around permanent weigh stations.

Mobile Enforcement

Most closely related to the STARS investigation, a study performed by Ruback and Middleton (1999) demonstrated a direct approach for using WIM/AVC data to improve the efficiency of vehicle weight enforcement efforts. In this study, a mobile enforcement officer was equipped with a computer that received WIM data directly via an Internet connection. When an overweight truck passed over a WIM scale, an enforcement officer in the vicinity was notified almost immediately. Hence, a greater portion of the enforcement officer's time was spent capturing overweight trucks rather than searching for violators based on experience and intuition, thus improving enforcement efficiency. This mobile enforcement system can be implemented using relatively inexpensive equipment, but it requires fast and reliable hardware and software to accommodate the required rapid information exchange between the WIM system and the mobile computer.

Though not formally documented, the State of New York (2002) is reportedly using a similar approach to that investigated by Ruback and Middleton (1999) for WIM-based weight enforcement. State troopers can identify overweight vehicles in real-time using laptop computers connected to WIM systems. The lane of travel, the number of axles and each axle's weight are transmitted to a mobile officer.

Pavement Preservation

Enforcement-related benefits attributable to the use of WIM/AVC technology are accompanied by pavement preservation benefits. A reduction in the proportion of overweight vehicles or the severity of the overweight violations results in a reduction in the overall traffic loading (ESALs) experienced by a pavement over its service life.

In a study of an augmented WIM system in Texas, trucks accounted for nearly 90 percent of the ESALs subjected to the pavement, but made up less than 16 percent of the traffic stream (Garner and Lee 1995). The study was comprehensive and considered nearly all trucks, both legal and overweight; data was collected 24 hours per day, 7 days per week for all but a few days per year.

In a study performed by Najafi, et al. (1996) for the Florida Department of Transportation (FDOT), WIM data was analyzed to generate average truck damage factors and average weights for each truck classification. They calculated the volume; average weight and minimum, maximum and average damage factors for seven classes of trucks at nine sites. The calculated damage factors for each type of truck show that roadway damage caused by trucks increases proportionately to the load in ESALs raised to the fourth power. Results also indicate the Class 9 trucks had the highest representation and result in the greatest pavement damage though the damage factor for Class 7 trucks is much higher than that of other truck types.

Hicks, et al. (1999) considered the impacts of increased truck loads on both existing and new roads. The authors concluded that if truck size and weight increased and pavement maintenance does not change, as much as 80 percent of the pavement life could

be lost. If pavement maintenance practices are in fact, altered to accommodate the increase in loads, both new and reconditioned pavements would require up to 2.5 inches of additional thickness.

An earlier study conducted by Fekpe, et al. (1995) suggested that efforts to compare pavement loading impacts of alternative truck weight limits have met with limited success because of uncertainty in inputs. Further, the effects of enforcement on the resulting vehicle weights have not been adequately addressed; enforcement is a critical factor in assessing pavement impacts. Fekpe, et al. suggested alternative parameters for evaluating pavement-loading impacts of alternative truck weight limits and enforcement levels including equivalent pavement loadings, truck load factors (average ESALs per truck), ESALs per payload, ESAL-kilometers, and ESAL-kilometers per payload. Parameters considering total pavement loading and the amount of payload provide a more objective assessment than the average load per truck alone. Pavement cost implications of alternative weight limits and enforcement levels were illustrated using costs per ESAL-kilometer for representative conditions in Ontario, Canada; in terms of pavement costs resulting solely from axle loads, substantial savings are achievable if strict enforcement schedules are implemented.

Engineering and Planning

For engineering and planning applications, WIM/AVC technologies provide a large amount of data for individual highway vehicles, such as axle spacing and weights,

vehicle length, speed and headway. Because of their unobtrusiveness and continuous operation, unbiased, statistically reliable data can be easily obtained.

Data Applications and Sharing

While numerous studies have been published recently expressing the benefits of WIM/AVC data for non-pavement or enforcement related applications, a second area for publication addresses the handling of this data with respect to sharing and processing.

The data-related needs of various Pennsylvania Department of Transportation (PennDOT) offices and bureaus were first identified through a survey questionnaire conducted by Sebaaly, et al. in 1991. PennDOT uses WIM/AVC data to perform several analyses, including number of vehicles weighed versus number counted; average gross, loaded and cargo weights; ESALs by truck type; twenty-year ESAL estimates; distribution of gross vehicle weights and number of trucks exceeding standard load limits. The various PennDOT offices and bureaus requested WIM/AVC data monthly and semiannually and reported graphically and tabularly by hours, days and months.

Similarly, Hajek, et al. (1992) identifies a number of specific application areas include planning and programming of transportation facilities, pavement design and rehabilitation, apportionment of pavement damage, compliance with vehicle weight regulations, development of geometric design standards, compliance and regulatory policy development of truck dimensions, safety analysis, traffic operation and control and analysis related to highway bridges. The usefulness of WIM/AVC data crosscuts the organizational structure of transportation agencies. Hajek, et al. suggests that WIM/AVC

data should be considered "corporate" data and should be managed accordingly with facilitated data storage and retrieval as a service to potential users.

A second report by Hajek, et al. (1994) demonstrates the potential of WIM/AVC data specifically for traffic safety analysis. The objective was to show, by practical examples, that WIM/AVC data are useful and indeed indispensable for fundamental safety-related traffic analysis. Examples include determination of truck exposure rates and evaluation of vehicle speed and headway distributions as a function of highway facility, vehicle type, daytime and nighttime conditions and truck load. WIM/AVC technologies have also been used as a primary component of speed advisory systems for potentially hazardous conditions, such as long steep downgrades or sharp curves. According to the authors, it is imperative that those working in the traffic safety area are made aware of the potential of WIM/AVC data for traffic-related safety analysis and that this potential is further pursued.

Liu, Sharma and Anderson (2002) considered data shortcomings for the Saskatchewan Department of Highways and Transportation. With a focus on operations and planning, individual interviews revealed that the most important traffic data included average annual daily traffic (AADT), percent trucks in the traffic stream and truck volume growth rates; separate growth rates for different types of trucks were desirable. More detailed data on vehicle classification, truck weight and configuration, truck traffic seasonal variation and goods movements was also requested. Goods movement data includes origin-destination and truck route data, commodity transported, cargo value crossing the border and type of truck used for grain movements in the Province. The

authors recommended installation of sufficient continuous WIM/AVC systems on the highway system to remedy the data shortcomings cited by planning and operations personnel.

Schmoyer and Hu (1996) investigated the potential for using WIM/AVC data from multiple New England states in a common resource data pool. Of particular interest were the possible analytical simplifications of combining vehicle classes or combining roadway functional classes. Adjusting for seasonal and day-of-week effects was also a concern. Preliminary conclusions suggest that from the perspective of vehicle load estimation, there is little advantage to combining vehicle classes. However, analysis of both the WIM and AVC data suggests that differences among functional classes are sufficient to warrant against combining them. The authors conclude that even without these simplifications, data sharing among states is a good idea. The analysis method used here, one-way analysis of variance, is reasonably simple to use and provides an accounting for statistical error; because data sharing means cross-state extrapolation, the combined data should not be used without a proper statistical accounting for extrapolation error.

Most recently, the Wisconsin Department of Transportation (2000) investigated the potential for data sharing between planning and enforcement divisions. The Wisconsin Department of Transportation (WDOT) has a long history of using WIM/AVC technology for planning purposes. Within WDOT, the Division of State Patrol also uses WIM/AVC technology for weight enforcement of commercial vehicles. The Planning Division of WDOT has been reluctant to allow shared use of WIM/AVC sites; if these

sites are used jointly for enforcement, commercial vehicles may avoid these locations resulting in unrepresentative data samples. According to the same study, national experience suggests considerable success in sharing WIM/AVC technology and data. WDOT reported that Michigan effectively uses the same data resources for varied purposes without adverse effects on the data collected for planning. They reported that Indiana also found that a cooperative partnership between planning and enforcement benefits the entire program. Commercial vehicles can be screened real-time; overweight violations can be acted upon at the time of the violation; further damage to the infrastructure can be avoided by removing the overload from the roadway. Both planning and enforcement are able to achieve their respective goals and objectives.

Data Storage and Processing

In the previously described study conducted for the Pennsylvania Department of Transportation, Sebaaly, et al. (1991) also considered the issue of processing, analyzing and storing WIM/AVC data. WIM/AVC systems generate large amounts of data that require tremendous time and effort to convert it into appropriate formats. The authors recommended development of five computer programs to analyze and report the WIM/AVC data.

In a more focused application, Wu (1996) used truck weight data collected from WIM/AVC sites to estimate truck load factors for pavement design purposes. Wu presents a conceptual procedure that uses WIM data to derive ESAL factors for different types of trucks.

Similarly, Folwell and Stephens (1997) developed a computer program that processes WIM/AVC data into a format usable by the Montana Department of Transportation (MDT). The program calculates ESAL factors by vehicle configuration, average vehicle weights by configuration and indicators of WIM system performance for WIM/AVC sites. This information is available both annually and for select time windows. The program also identifies and describes the overweight vehicles found in the data; routines could be developed to directly support weight enforcement efforts. For example, reports showing the correlation between weight enforcement activities and observed volumes of overweight vehicle traffic can be made.

The Maine State Police are identifying chronic overweight vehicle situations by graphically analyzing WIM data using American Image, Inc. (2002) technologies referred to as JOHO. The Maine Department of Transportation (MDOT) has recently installed 12 WIM sensors at various strategic locations around the state. JOHO updates a series of images for internal use each time data is downloaded from the WIM/AVC sensors. The State Police are still investigating methods through which the efficiency of their weight enforcement efforts can be improved using the results of their analyses.

With increased capabilities for WIM/AVC data processing, there has been an accompanying focus on the quality of WIM/AVC data. If the WIM sensors read too low, the recorded axle loads result in insufficient fatigue calculations and pavement thickness designs that are too thin leading to premature pavement failure. The reverse leads to excessive pavement thickness designs resulting in unnecessary upfront expenditures.

With data quality as the focus, Southgate (1989) initiated a study to develop a method to determine the quality of WIM/AVC data, firm guidelines for making judgment calls and a method to "adjust" the data to fit within those guidelines. Southgate's examination of data from 78 WIM sites across eight states revealed extreme differences in axle loads for 5-axle semi-trailer trucks. It was suggested that this adjustment method be used by the Long Term Pavement Performance (LTPP) of the Strategic Highway Research Program (SHRP) to improve the quality of the data already in the data bank as well as data sets received in the future.

Garner and Lee (1995) considered efforts to improve WIM/AVC data quality in the field rather than following data capture. Their augmented WIM system comprised an inductance loop detector, a weigh pad in each wheel path, an infrared sensor unit for each lane and two thermocouples for capturing pavement temperature data. The augmented design allowed for collection of standard WIM data, but minimized the number of vehicle presence sensors required for operation, and permitted collection of additional data including single or dual tire type on an axle and the vehicle's lateral position in the lane of travel. These new elements were collected using the infrared light beam. If a vehicle passes indirectly over a WIM sensor, erroneous readings can be recorded. When the augmented WIM system suspects that a vehicle did not pass directly over the scale, the lateral position of the vehicle can be used to calculate a reasonable estimate of both the axle weight and gross vehicle weight. Further, information pertaining to single or dual tire type results in more accurate ESAL calculations.

Most recently, Walters and Whitford (1998) investigated the WIM/AVC data accuracy required to accurately determine equivalent single axle loads (ESALs). More specifically, the authors investigated whether the ESALs calculated using axle weights and counts derived from weight and classification data were of sufficient accuracy. Regression analysis of single and tandem axle data versus ESALs showed remarkably consistent behavior and the authors concluded that all of the WIM technologies were performing within national standards. Further, the data reduction approach was consistent with the level of acceptable errors.

Implications for this Investigation

The historical literature reviewed in support of this investigation has been twofold in focus, considering WIM/AVC applications in both enforcement and pavement preservation activities and engineering and planning activities. With respect to enforcement activities, percent of overweight vehicles, capture and violation rates, time of day/day of week distributions and vehicle configuration are key data elements for monitoring the effectiveness of efforts. Truck weight and volume data is critical for ESAL calculations from which pavement conditions and pavement life are determined.

Few previous investigations have attempted to dispatch enforcement resources in response to WIM/AVC generated information on overweight vehicle movements. Instead, WIM/AVC technologies have been used to sort non-compliant vehicles from the traffic stream and direct them to a weigh station, thereby improving the efficiency of

existing enforcement facilities. WIM/AVC technologies have also been used to investigate the avoidance of static weigh stations.

Of the investigations focused on enforcement dispatch, the emphasis has historically been on use of real-time data with only spot location applications. STARS appears to be the first of its kind to use *historical* WIM data to redirect and improve enforcement efforts and address long-term issues related to commercial vehicles by changing their loading behaviors.

CHAPTER 3

METHODOLOGY

When considering the effects of the STARS program on both enforcement efforts and engineering and planning activities, the following basic five-step methodology was employed for each evaluation:

(1) identify required data elements and sources to support performance measures of interest

(2) examine and measure existing performance and conditions (before full implementation of STARS) to establish a baseline

(3) examine and measure performance and conditions after STARS implementation

(4) analyze and interpret the before and after data

(5) document the changes attributable to STARS.

Following a description of the WIM/AVC site locations, this Chapter further details the methodologies used in this investigation.

WIM/AVC Site Locations

STARS is a statewide program having a network of 26 permanent WIM/AVC sites supplemented by 64 additional sites that are to be operated intermittently on a three-year cycle using fully portable WIM equipment. The portable sites were not utilized as part of this investigation, and only 16 of the 26 permanent sites were considered. Several of the permanent STARS WIM sites had various problems with the WIM equipment, resulting

in "bad" data or a loss of data. Those WIM sites with significant data problems were subsequently excluded from the final evaluation. Table 1 indicates those sites included in the STARS evaluation. These same sites are depicted graphically in Figure 1. Sites excluded from the final evaluation include Bad Route, Big Timber, Twin Bridges, Troy-Libby and both Mossmain sites.

Some of the sites included in the final analysis also experienced problems with the WIM equipment but these problems were sporadic and short-term in nature, often affecting a single month. The unaffected months provided an adequate representation of commercial vehicle activity at these sites. A detailed activity log describing each maintenance visit to the WIM/AVC sites (provided by MDT) was used to determine the source of data problems. Using this information and data from prior and subsequent months at the same site, a determination was made to include or exclude the month in question in the final STARS evaluation. None of the sites selected for inclusion had more than two questionable months.

In one case, it was decided to consider WIM/AVC data from two sites as a single site. The Four Corners site and the Gallatin site were considered singularly to account for months where there were problems with data at either site; data from the Four Corners site was used for the months of July, August and September and data from the Gallatin site was considered for all other months. This combination was thought feasible due to the close proximity of the two sites.

Table 1. Proposed WIM Site Information

Permanent WIM Site	Route	Included in Final Analysis?
Townsend	US Highway 287	Yes
Decker	Highway 314	Yes
Bad Route	Interstate 94	No
Manhattan	Interstate 90	Yes
Arlee	US Highway 93	Yes
Four Corners	US Highway 191	Combined with Gallatin
Gallatin	US Highway 191	Combined with Four Corners
Big Timber	Interstate 90	No
Galen	Highway 273	Yes
Broadview	State Route 3	Yes
Miles City East	US Highway 12	Yes
Ulm	Interstate 15	Yes
Ryegate	US Highway 12	Yes
Stanford	US Highway 87	Yes
Fort Benton	US Highway 87	Yes
Havre East	US Highway 2	Yes
Twin Bridges	State Route 41	No
Paradise	State Route 200	Yes
Mossmain	Interstate 90	No
Troy-Libby	US Highway 2	No
Culbertson	State Route 16	Yes
Lima	Interstate 15	Yes
Mossmain	Interstate 90	No

Affected Mileage

Enforcement activities at a given STARS site were presumed to influence vehicle activities over a segment of roadway of finite length that included that site. To determine changes in pavement damage and the costs attributable to STARS enforcement efforts, it is necessary to determine the amount of mileage that is affected by STARS activities at each WIM/AVC site. The extent of affected mileage was determined

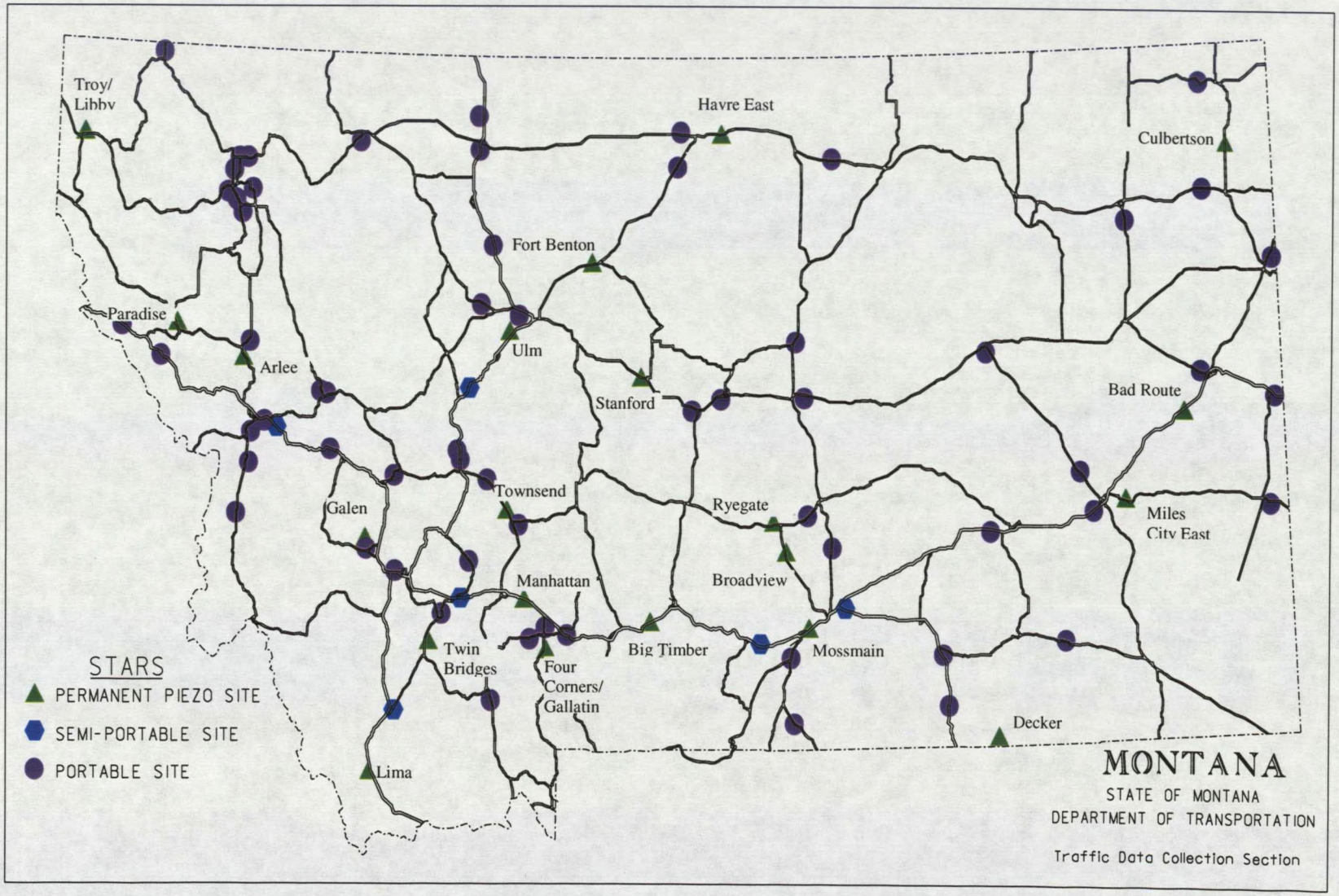


Figure 1. Location of Proposed STARS Weigh-in-Motion (WIM) Sites

using the roadway distance from the WIM/AVC site to an adjacent junction with a highway, interstate or state line upstream and downstream of the WIM/AVC site. At these locations, truck traffic volumes may significantly change and confound the STARS program effects. In some instances, the affected mileage was extended in either direction beyond the junctions; if truck traffic remained constant through the nearest junction, the affected mileage was extended to a subsequent junction. A summary of affected mileage for each WIM/AVC site is included in Table 2. Instances where the affected mileage was adjusted based on constant truck volumes are noted as "Comments".

Data Collection and Processing

Extensive quantitative data and more limited qualitative data were collected to support the determination of STARS program effectiveness in the areas of enforcement and engineering and planning.

Enforcement

Truck weight and classification data was automatically collected at the 16 STARS sites statewide using various WIM/AVC systems and processed using the Measurement of Enforcement Activities Reporting System (MEARS).

Table 2. Summary of Affected Mileage for each STARS WIM/AVC Site

WIM Site	Route	System[1]	From:		To:		Mileage[2]
Townsend	US 287	NHS Non-Interstate	I-15	Helena	I-90	W. of Three Forks	62
Comments[3]: 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	NHS Interstate	US 287	W. of Three Forks	SR 85/US 191	Belgrade	23
Arlee	US 93	NHS Non-Interstate	I-90	W. of Missoula	SR 200	Ravalli	27
Four Corners/ Gallatin	US 191	NHS Non-Interstate	I-90	Belgrade	MT/ID Border		98
Comments[3]: 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	NHS Non-Interstate	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	NHS Interstate	US 87/SR 3	Great Falls	US 12	Helena	86
Comments[3]: Low truck volumes on US 287 (S. of Craig).							
Ryegate	US 12	NHS Non-Interstate	US 191	Harlowton	SR 3	Lavina	45
Stanford	US 87	NHS Non-Interstate	I-15	Great Falls	US 191	W. of Moore	88
Comments[3]: Low truck volumes on US 89 (E. of Belt) and SR 80 (Stanford).							
Fort Benton	US 87	NHS Non-Interstate	I-15	Great Falls	US 2	Havre	112
Comments[3]: Low truck volumes on SR 80 (Fort Benton).							
Havre East	US 2	NHS Non-Interstate	US 87	Havre	SR 24	Glasgow	158
Comments[3]: 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	NHS Non-Interstate	SR 200	Sidney	SR 5	Plentywood	82
Comments[3]: Truck volumes stay consistent through intersection with US 2 (Culbertson).							
Lima	I-15	NHS Interstate	SR 41	Dillon	MT/ID Border		64

[1] System names determined from MDT Montana Highway System Map.

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

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

WIM/AVC Equipment. WIM/AVC equipment is fully automated and performs continuously, providing sufficient data for a robust evaluation of the STARS program effectiveness. For this investigation, both bending plate WIM systems (manufactured by PAT America) and piezoelectric WIM systems (manufactured by Electronic Control Measurement (ECM)) were utilized, though the majority of sites were equipped with piezoelectric technologies. Table 3 lists the WIM technology used by site.

Table 3. WIM Equipment by Site

STARS WIM Site	WIM Equipment	
	Bending Plate	Piezoelectric
Townsend		✓
Decker		✓
Manhattan		✓
Arlee		✓
Four Corners/Gallatin		✓
Galen		✓
Broadview		✓
Miles City East		✓
Ulm		✓
Ryegate		✓
Stanford		✓
Fort Benton		✓
Havre East		✓
Paradise		✓
Culbertson	✓	
Lima	✓	

MEARS Software. The WIM/AVC data collected at the various STARS sites was automatically analyzed using the Measurement of Enforcement Activities Reporting System (MEARS) computer software program specifically developed for the Montana Department of Transportation. MEARS generates reports on the commercial vehicle

activity by site and month, although reports for the entire year are also available. Typical MEARS reports for the Townsend WIM/AVC site for the month of October 2001 are provided as an example in Figures 2 and 3. Figure 2 provides information on the number of total and overweight commercial vehicles in the traffic stream, the percent of overweight vehicles, the average percent overweight, the direction of travel, etc. for individual vehicle configurations. Figure 3 depicts the number of overweight commercial vehicles by time of day for a Class 9-1 truck.

Engineering and Planning

Qualitative information was gathered to determine the STARS program effects on engineering and planning activities. A non-scientific survey questionnaire was distributed to various divisions within the Montana Department of Transportation with the primary goal of detailing the extent of benefits that may result from expanded and improved truck-related data. In particular, representative responses were sought from the following areas:

- Planning
- Engineering
- Motor Carrier Services
- Pavements and Materials
- Geometric Design
- Safety and
- Bridges.

Report Period 01-OCT-2001 **To** 31-OCT-2001

Site TOWNSEND

Class-Sub Class	GVW Limits	Total # CV in Sample	Total # OW CV in Sample	Cumulative total of OW values	% OW CV	Avg. OW KIPS/ OWC
Class 4 - 1	32 k	389	3	5.19	0.77	1.73
Class 4 - 2	46 k	193	12	75.46	6.22	6.29
Class 5 - 1	32 k	787	4	7.15	0.51	1.79
Class 5 - 2	52 k	26	0	0.00	0.00	0.00
Class 5 - 3	66 k	684	0	0.00	0.00	0.00
Class 5 - 4	74 k	51	0	0.00	0.00	0.00
Class 6 - 1	46 k	939	58	389.77	6.18	6.72
Class 7 - 1	54 k	16	7	34.26	43.75	4.89
Class 7 - 2	62 k	3	2	17.98	66.67	8.99
Class 7 - 3	62 k	0	0	0.00	0.00	0.00
Class 8 - 1	52 k	125	0	0.00	0.00	0.00
Class 8 - 2	66 k	244	2	7.77	0.82	3.89
Class 9 - 1	80 k	3797	505	2624.10	13.30	5.20
Class 9 - 2	86 k	691	49	170.32	7.09	3.48
Class 9 - 3	74 k	1	0	0.00	0.00	0.00
Class 10 - 1	88 k	609	78	603.93	12.81	7.74
Class 10 - 2	96 k	61	16	111.96	26.23	7.00
Class 10 - 3	96 k	79	58	733.65	73.42	12.65
Class 11 - 1	92 k	142	0	0.00	0.00	0.00
Class 12 - 1	106 k	234	1	0.04	0.43	0.04
Class 13 - 1	120 k	1031	33	172.97	3.20	5.24
Class 13 - 2	131 k	404	59	352.30	14.60	5.97
Class 13 - 3	120 k	949	52	289.87	5.48	5.57
Class 13 - 4	131 k	0	0	0.00	0.00	0.00
Totals		11455	939	5596.72	8.20	5.96

CV Violating by Day-of-Week and Direction

Day-of-Week	% OW CV		# CV Violating	
	East	West	East	West
Sunday	60.00	40.00	27	18
Monday	66.67	33.33	90	45
Tuesday	69.36	30.64	120	53
Wednesday	62.98	37.02	131	77
Thursday	52.00	48.00	91	84
Friday	60.96	39.04	89	57
Saturday	57.89	42.11	33	24

Figure 2. Typical MEARS Report.

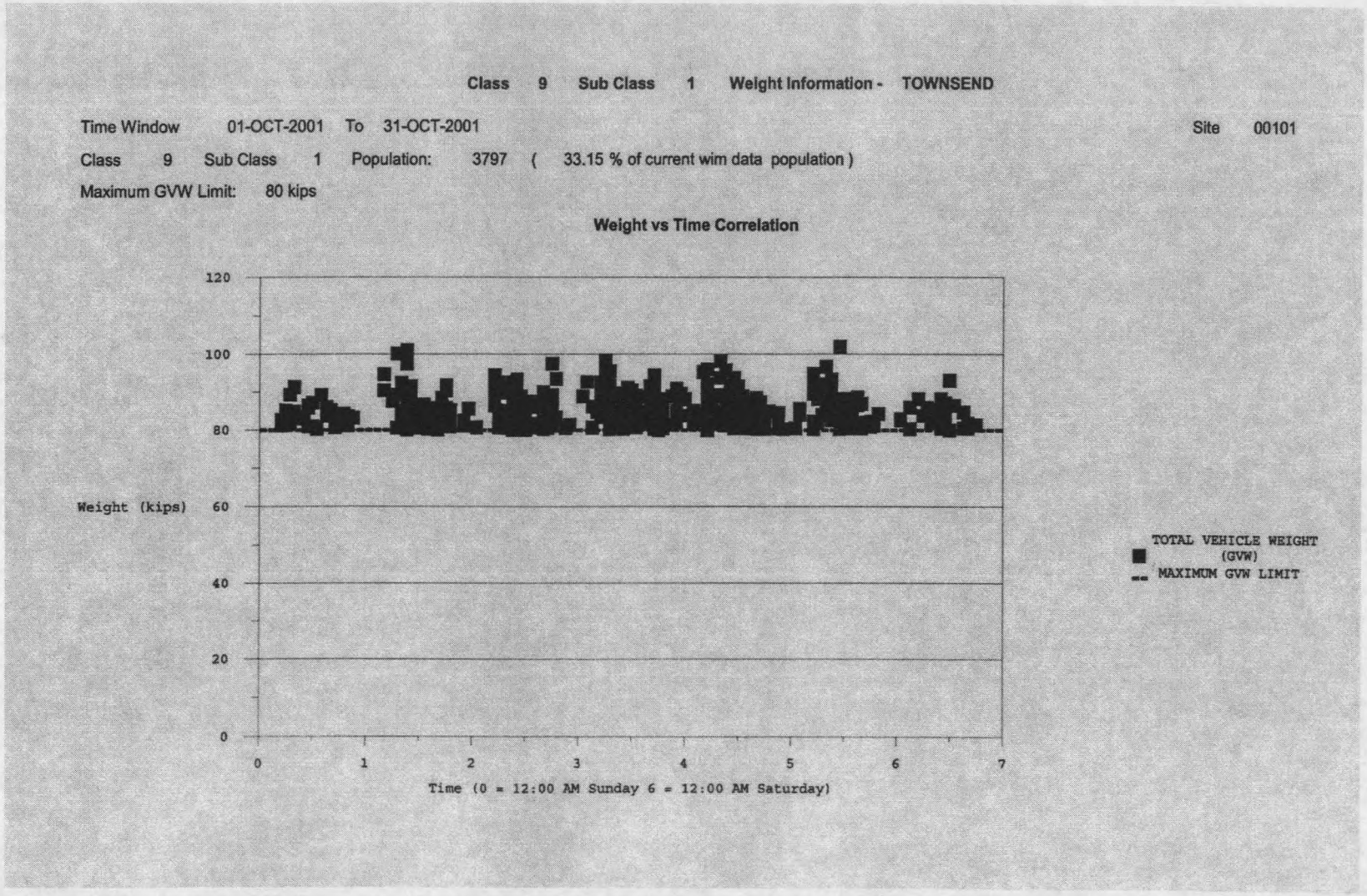


Figure 3. Typical MEARS Report.

The survey questionnaire prompted responses on data use, data elements, data sources, data quality, and desired data improvements. The questionnaire also asked for additional information on the effects of improvements in truck-related data quantity and quality. The final question on the survey asked MDT personnel to specify the degree to which new truck-related data provided through STARS would benefit their day-to-day activities.

Analysis

Analysis activities for this investigation focused on the enforcement and resultant pavement preservation effects of the STARS program. STARS program effects on engineering and planning activities were qualitative in nature and hence, required no formal analysis.

Enforcement

The enforcement-related objective of the STARS program was to reduce the overall proportion of overweight trucks in the traffic stream and reduce the average overall weight exceedence. This reduction in overweight truck volumes and weight exceedence accomplishes another objective of the STARS program; to reduce the amount of pavement damage from overweight vehicles (measured in ESALs) and the associated cost.

To accomplish these objectives, a step-by-step procedure was developed to identify and prioritize the locations within the state that would benefit most from focused

enforcement (i.e., the locations within the state experiencing the greatest pavement damage from overweight activity). First, the amount of pavement damage, in overweight ESALs, was calculated for each WIM/AVC site and by month during the baseline year. These calculations were based on the AASHTO ESAL method that relates axle passage to pavement deterioration. The AASHTO method uses load equivalency factors to develop quantitative pavement demands from vehicle axle loads. The following equations from AASHTO (1972) were used to perform all of the ESAL calculations for the STARS evaluation:

$$G_t = \log [(4.2 - p_t)/(4.2 - 1.5)]$$

where

p_t is the serviceability which was equal to 2.5 for all calculations and

G_t is the ratio of loss in serviceability at time t to the potential loss taken to a point where $p_t = 1.5$.

And

$$\beta = 0.40 + (0.081(L_1 + L_2)^{3.23})/((SN + 1)^{5.19} L_2^{3.23})$$

where

β is a function of design and load variables that influence the shape of the serviceability curve,

L_1 is the load on one single axle or on one tandem-axle set in kips,

L_2 is the axle code, which is equal to 1 for a single axle and 2 for a tandem axle and

SN is the structural number, which was equal to 4 for all calculations.

The AASHTO traffic equivalence factors were calculated using the following equations for single axles and tandem axles, respectively.

$$\log W_{tx}/W_{t18} = 4.79 \log (18 + 1) - 4.79 \log (L_X + 1) + G_t/\beta_X - G_t/\beta_{18}$$

and

$$\log W_{tx}/W_{t18} = 4.79 \log (18 + 1) - 4.79 \log (L_X + 2) + 4.33 \log 2 + G_t/\beta_X - G_t/\beta_{18}$$

where

W_{tx} is the load application for axle load, L_X, and

W_{t18} is the 18-kip single-axle load application.

The ratio of these two values gives the relationship between any axle load, L_X, single or tandem, and an 18-kip single-axle load and

β_X and β_{18} are the values for β with an axle load, L_X, and an 18-kip single-axle load, respectively.

These equivalency factors were then multiplied by the number of axles at each axle weight. These products were then summed to get the total number of ESALs for each vehicle class, for each site and for each month of the baseline year (May 2000 to April 2001). These results were depicted graphically to more easily identify and prioritize focused enforcement sites each month. Figure 4 provides an example for the baseline month of October 2000. Manhattan, Townsend, Four Corners, Stanford and Decker were selected for focused enforcement during the evaluation month of October 2001 based upon the amount of pavement damage observed the previous year. Note that Ryegate and Miles City East experienced higher levels of pavement damage than Decker in the baseline year but were not selected for focused enforcement. The vehicles contributing to

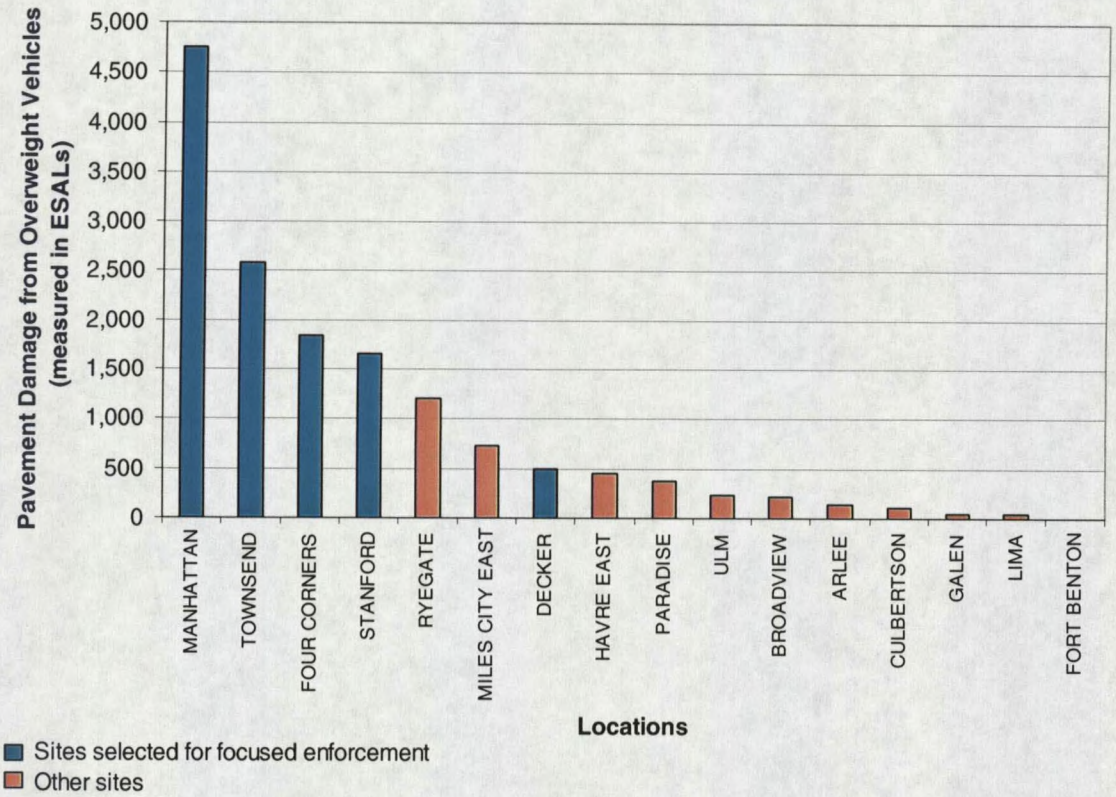


Figure 4. Typical Pavement Damage (measured in ESALs) for each STARS Site for October 2000 (Baseline Year).

the pavement damage at these sites were technically over legal weight limits but within the State's weight tolerance and hence, uncitable.

For the five sites selected for focused enforcement, MEARS reports were subsequently used to determine the vehicle configuration(s) responsible for the pavement damage and their respective time and direction of operation. Prior to each month of focused enforcement, a proposed enforcement schedule, similar to the one provided in Table 4, was sent to MDT's MCS Division. This schedule, derived from historical WIM/AVC information, was then used to guide the dispatching and scheduling of mobile enforcement officers for the same month, one year later in 2001-2002. A summary of the STARS enforcement sites is given in Table 5.

Once this process was completed for the entire enforcement year (May 2001 to April 2002), any changes attributable to STARS were determined by comparing the WIM/AVC data from the baseline year to the WIM/AVC data from the enforcement year. The proportion of overweight vehicles for each site by month was calculated and compared for the baseline year and the enforcement year. Again using the AASHTO method, the total number of ESALs was calculated for the enforcement year by vehicle class, month and site. These results were compared with those calculated for the baseline year. Statewide averages and averages by configuration were also calculated before and after the implementation of the STARS program. Because truck traffic volumes are not consistent from year to year, all calculations were normalized by multiplying the results

Table 4. Typical Monthly Enforcement Schedule Generated from WIM Data Analysis

Site	Day of Week	Critical Time of Day	Direction of Travel and Vehicle Configuration(s)
Townsend	Monday	8:00 am to 4:00 pm	9, 10 East or West; 13 West
	Tuesday	8:00 am to 4:00 pm	9 East or West; 10 East, 13 West
	Wednesday	8:00 am to 4:00 pm	9, 10 East or West; 13 West
Decker	Monday	8:00 am to 8:00 pm	13, 10 North; 9 North or South; 6 North
	Wednesday	8:00 am to 8:00 pm	13, 10 North; 9 North or South
	Friday	8:00 am to 8:00 pm	13, 10 North; 9 North or South
Gallatin	Monday	noon to midnight 4:00 am to noon	9, 6 North or 9, 13 South
	Tuesday	noon to midnight	9, 6 North
	Friday	noon to midnight	9, 6 North
Manhattan	Monday	8:00 am to 8:00 pm	10, 9 West; 6 East
	Wednesday	8:00 am to 8:00 pm	10, 9 West; 6 East
	Thursday	8:00 am to 8:00 pm	10, 9 West; 6 East
Stanford	Monday	Noon to midnight	9, 10 East or West
	Tuesday	Noon to midnight	9, 10 West
	Friday	Noon to midnight	9, 10 West

Table 5. Summary of STARS Enforcement Sites

	2001								2002			
Site	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
Townsend	X	X	X	X	X	X	X	X			X	X
Decker					X	X				X		
Bad Route	X		X	X								
Manhattan						X			X			
Arlee			X						X			
Four Corners												
Gallatin	X	X X	X	X	X	X	X	X X	X	X	X	X
Big Timber	X	X										
Galen												
Broadview												
Miles City East				X								
Ulm							X	X	X	X		
Ryegate					X		X	X	X	X	X	X
Stanford	X	X	X	X	X	X	X			X	X	X
Fort Benton												
Havre East												
Paradise												
Moss Main												
Culbertson												
Lima												

of the various calculations by the ratio of the enforcement year truck volumes to the baseline year truck volumes.

Some risk lies in the comparison of a single baseline year to a single evaluation year. Hence, a two-sample t-test was conducted to measure the statistical significance of the calculated reduction in pavement damage (in ESALs). The underlying hypothesis for this test states that the mean pavement damage during the baseline year is equal to the mean pavement damage of the enforcement year. This hypothesis test assumes that the samples collected for each of the two years are independent. Further, the formulation of the test statistic varies depending on whether or not the variances of the two samples are equal. To confirm this second assumption, an F-test was used:

$$F = \frac{S_1^2}{S_2^2}$$

where:

S_1 is the standard deviation of the baseline year sample and

S_2 is the standard deviation of the enforcement year sample.

If the variance equality assumption is accurate, the test statistic for the two-sample t-test is:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{s\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

where:

x_1 is the mean pavement damage (in ESALs) for the baseline year,

x_2 is the mean pavement damage (in ESALs) for the enforcement year,

n_1 is the size of the sample collected during the baseline year,

n_2 is the size of the sample collected during the enforcement year and

s is the pooled standard deviation for the two samples given as:

$$s = \sqrt{\frac{(n_1 - 1) * s_1^{\,2} + (n_2 - 1) * s_2^{\,2}}{n_1 + n_2 - 2}}$$

where all variables are as previously defined.

Should the assumption of equal variances between the two samples prove to be false, the test statistic for the t-test becomes:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^{\,2}}{n_1} + \frac{s_2^{\,2}}{n_2}}}$$

where all variables are as previously defined. In each case, a 95 percent confidence level was used to accept or refute the hypothesis.

Costs were assigned against the changes in pavement damage before and following STARS implementation based on the fundamental cost to the state of constructing and maintaining the highway system. Highways are designed and built to withstand, among other things, a certain number of ESALs. Thus, a cost can be established for each ESAL that a highway is expected to carry. For this investigation, this cost was estimated from the results of a cost allocation study for the state highway system completed by Stephens and Menuez (2000). The total ESAL miles of highway use reported in that study over a three year period was divided by the pavement expenditures allocated against ESAL related demands to obtain the cost of providing highway service in dollars per ESAL per mile for each highway system (e.g., interstate, primary, secondary, etc.) in the state

highway network. The resulting costs were subsequently adjusted for inflation that has occurred since that study (which covered 1994 to 1996), to obtain costs of $0.05/ESAL/mile to $0.31/ESAL/mile for the year 2000-2001, depending on the system within the network. The appropriate unit cost at each site was subsequently multiplied by the change in ESALs at the site from the baseline year to the enforcement year and by the estimated length of highway (from Table 2) whose operations were affected by enforcement at the site to obtain the cost impact.

Lastly, the effectiveness of the STARS program was investigated with respect to citation issuance. One would suspect an increased rate of citation issuance resulting from focused enforcement efforts. A noted reduction in citation issuance, however, may suggest a more desirable change in commercial vehicle loading behavior. A confounding explanation for a decrease in citation issuance is the change in enforcement policy that was implemented during the STARS program evaluation that increased the allowable tolerance for a citable offense from seven to ten percent

Using data reported by MCS, the total number of citations per hour worked was calculated by quarter for both the baseline year and enforcement year. The results were compared to determine the effect that directed enforcement efforts had on the number of citations issued.

CHAPTER 4

RESULTS

Overall, the STARS program was found to be a success. Results are detailed below pertaining to:

- enforcement and
- engineering and planning.

Primary enforcement-related performance metrics considered changes in proportion of overweight vehicles, changes in pavement damage and changes in citation issuance. Each of the figures included in this Chapter were generated using data obtained from MEARS reports. It should be noted that a variety of different confounding factors could contribute to a change in commercial vehicle operations. For example, a large construction project may cause a dramatic increase in the number of heavily-loaded vehicles at a specific site during one year but not the next. Every opportunity was taken to identify and control for the effects of these confounding factors.

Enforcement Impacts

Recall that the effectiveness of the STARS enforcement program is based on a noted reduction in the proportion of overweight trucks in the traffic stream and/or a noted reduction in pavement damage measured in ESALs and associated cost. This section will further explore each of these issues, along with those of changes in vehicle weight

distributions, citation issuance activity and the overall statewide effect of focused enforcement.

One of the goals of the STARS-based focused enforcement effort was to affect long-term changes in vehicle loading patterns. Ideally there will be residual effects following a month of focused enforcement. While it is generally believed that the residual effects of enforcement activities are short in duration, it was thought that some longer-term alterations in vehicle loading patterns might result from the STARS enforcement effort since many of these focused efforts were in response to habitual overweight operations associated with routine freight movements. Further, the loading pattern of commercial vehicle behavior is likely affected for more than the specific vehicle types selected for targeted enforcement. This issue will be further discussed later in this Chapter.

Changes in Proportion of Overweight Vehicles in Truck Traffic Stream

A general reduction was observed in the percentage of commercial vehicles in the traffic stream operating overweight across the state during the year of focused enforcement. Although the reductions vary from site to site, it was observed that the greatest reductions generally occurred at the STARS enforced sites. This indicates that the use of STARS information to direct enforcement efforts was primarily responsible for this reduction in overweight commercial vehicles.

To facilitate examination of these focused enforcement effects, Figures 6 through 21 are grouped based on the number of months of focused enforcement for each site. More specifically, sites with more than six months, one to six months and sites without any

focused enforcement are described more fully below. Data points denoted in red represent the months that have potentially "bad" data or a loss of data. As previously mentioned, these points were considered in the data set for this investigation, but they will later be scrutinized as to their appropriateness for inclusion in the final analysis.

STARS Sites With More Than Six Months of Focused Enforcement. Figures 5 through 8 represent the STARS sites with anywhere from seven to twelve months of focused enforcement. With few exceptions, the proportion of overweight commercial vehicles at these sites during the enforcement year is generally lower than that of the baseline year. Those months that are not consistent with this observation are typically the last two months of the enforcement year and the first month after the enforcement year (May 2002). This may be attributable to a relaxed emphasis on enforcement nearing the end of the evaluation period. Referring to Figures 5 through 8, on of the most notable reductions in overweight vehicle percentages occur at Ryegate during the months of October through May (see Figure 7). Following a peak during the non-enforced month of October, there is a steady decrease in the percent of overweight vehicles in the traffic stream over several months of focused enforcement. There is also a potential residual effect in May 2002 following the enforcement year; the percent of overweight vehicles continues to decrease even though the focused enforcement concluded the previous month.

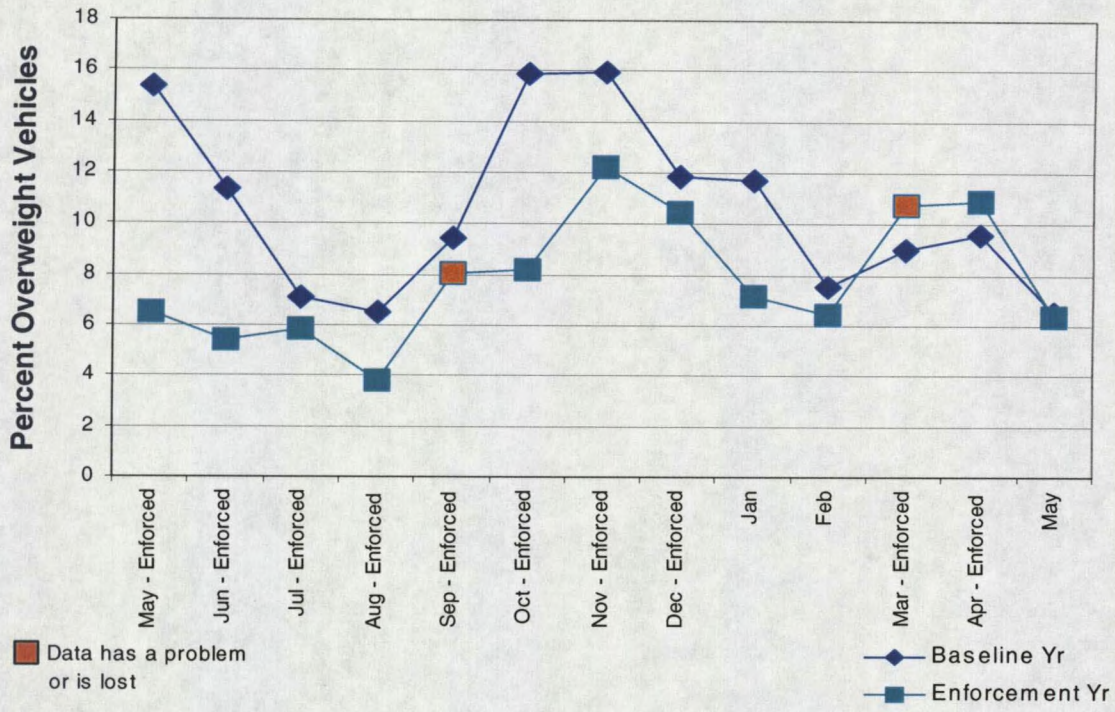


Figure 5. Percent Overweight Commercial Vehicles by Month at the **Townsend** STARS Site, Baseline and Focused Enforcement Years.

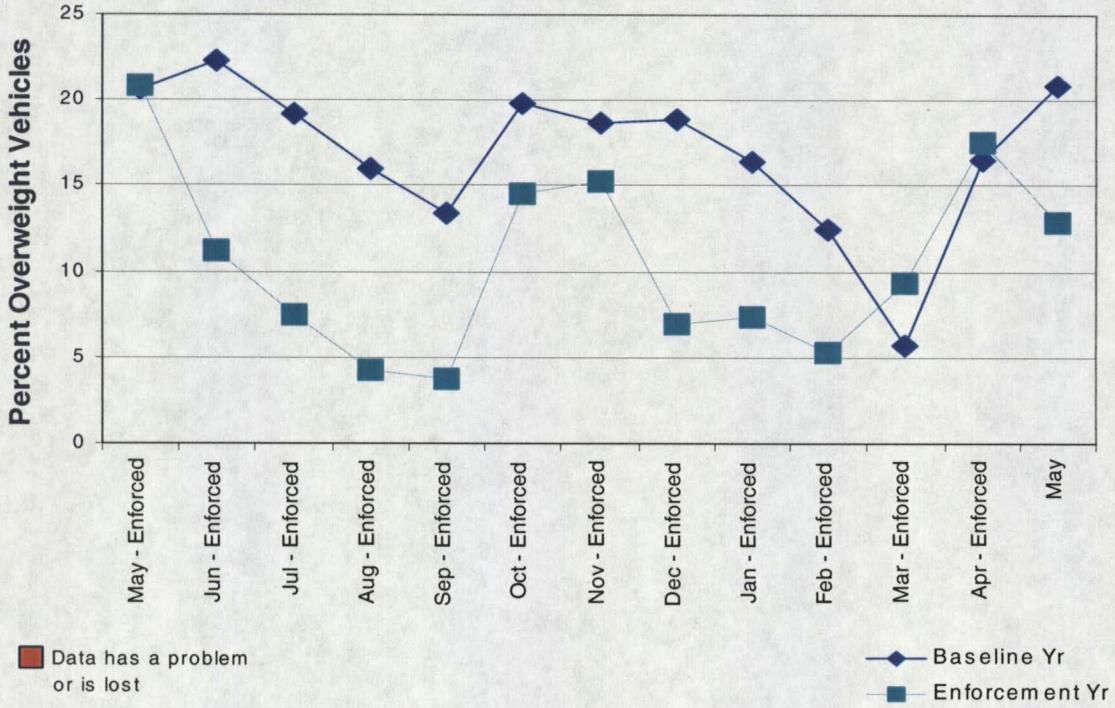


Figure 6. Percent Overweight Commercial Vehicles by Month at the **Four Corners/ Gallatin** STARS Site, Baseline and Enforcement Years.

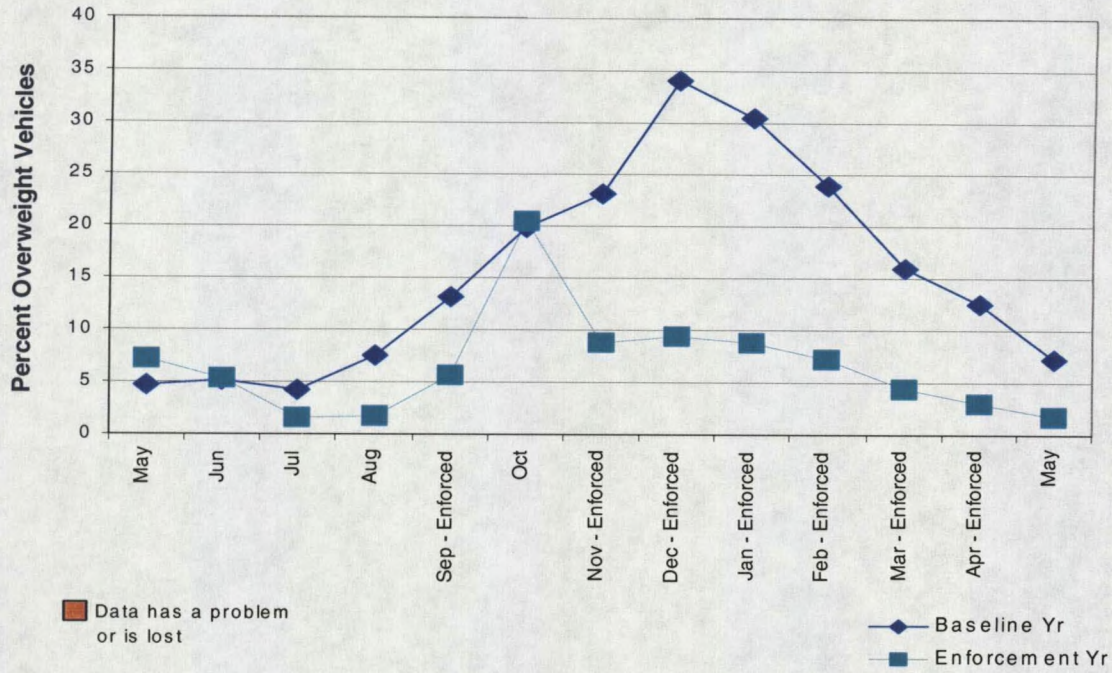


Figure 7. Percent Overweight Commercial Vehicles by Month at the **Ryegate** STARS Site, Baseline and Focused Enforcement Years.

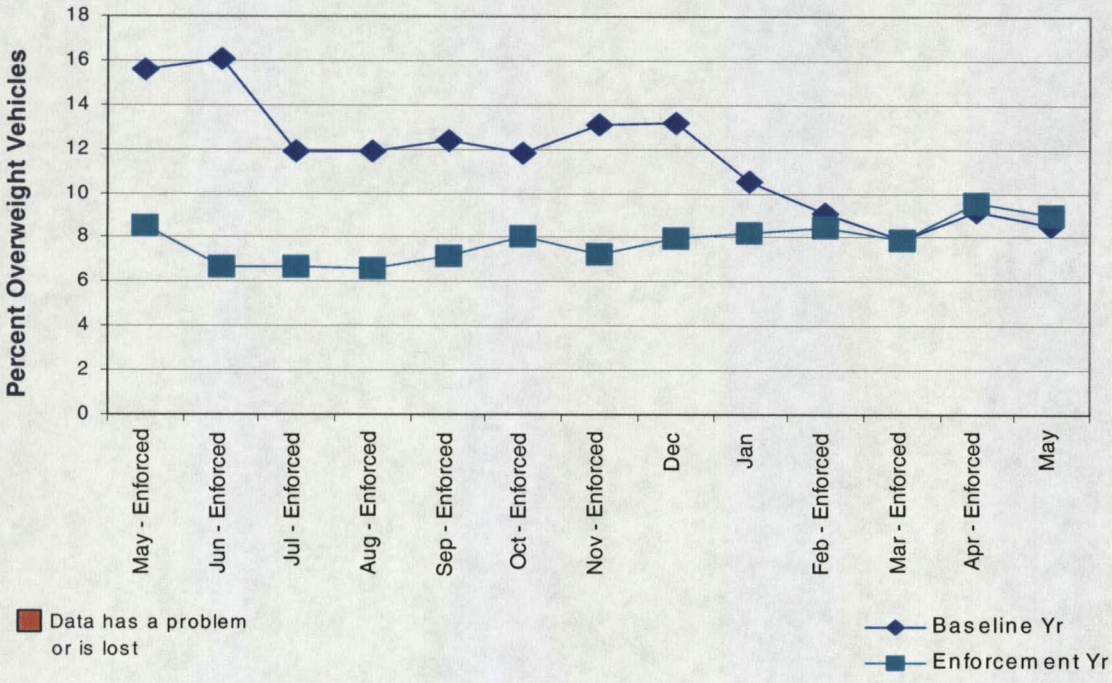


Figure 8. Percent Overweight Commercial Vehicles by Month at the **Stanford** STARS Site, Baseline and Focused Enforcement Years.

STARS Sites With One to Six Months of Focused Enforcement. Figures 9 through 13 depict the STARS sites with anywhere from one to six months of focused enforcement. As can be seen in these figures, the difference in the percent of overweight commercial vehicles between baseline and enforcement years is not as discernable as it was for those sites with more than six months of focused enforcement. In some instances, patterns of overweight activity can reasonably be explained based on months of focused enforcement activity, while in almost the same number of instances, explanations for observed behaviors are not so obvious.

The percent of overweight vehicles at Decker (see Figure 9) in the first focused enforcement month (September) clearly dropped relative to the previous month in the same year and the same month of the previous year (both of which were not targeted enforcement months). In October, this site was again selected for enforcement and the percentage of vehicles operating overweight remained well below that observed for same month the previous year with residual effects observed in November, which was not selected for targeted enforcement but experienced a decline in overweight vehicle activity. The percentage of vehicles operating overweight in the traffic stream subsequently increased in December to the levels observed in previous years. It is possible therefore, that the enforcement effort had one month of residual effect on overweight vehicle operations at this site.

A similar effect can be seen at Arlee in the enforcement month of January (see Figure11) where a decrease in the percent of overweight vehicles relative to the previous month and the same month the previous year is observed. Once again, a residual effect

can be seen in the subsequent non-enforced month of February at this site with the percent of overweight vehicles increasing in March. This effect can be observed again in the enforcement month of August at the Miles City East site (see Figure 12) with a potential residual effect occurring during the following non-enforced month of September.

From these observations alone, however, it is difficult to correlate all changes in overweight vehicle operations to STARS enforcement activities. Once again, referring to the Decker STARS site (Figure 9), focused enforcement efforts in February resulted in no apparent residual effect on the operation of overweight vehicles in the months following the enforcement activity. Further, the enforcement activity in February resulted in only a nominal reduction in overweight vehicles relative to the previous year, and in the month following the enforcement effort, the percent of overweight vehicles in the traffic stream actually increased (both with respect to the previous month and with respect to the same month the previous year). As mentioned above, this pattern of behavior (no obvious residual effect of enforcement efforts) was observed at several other sites.

STARS Sites Not Selected for Focused Enforcement. Figures 14 through 20 represent sites included in the STARS evaluation but that did not warrant focused enforcement. As can be expected, it is difficult to determine any trends between the lines representing the baseline and enforcement years at these sites.

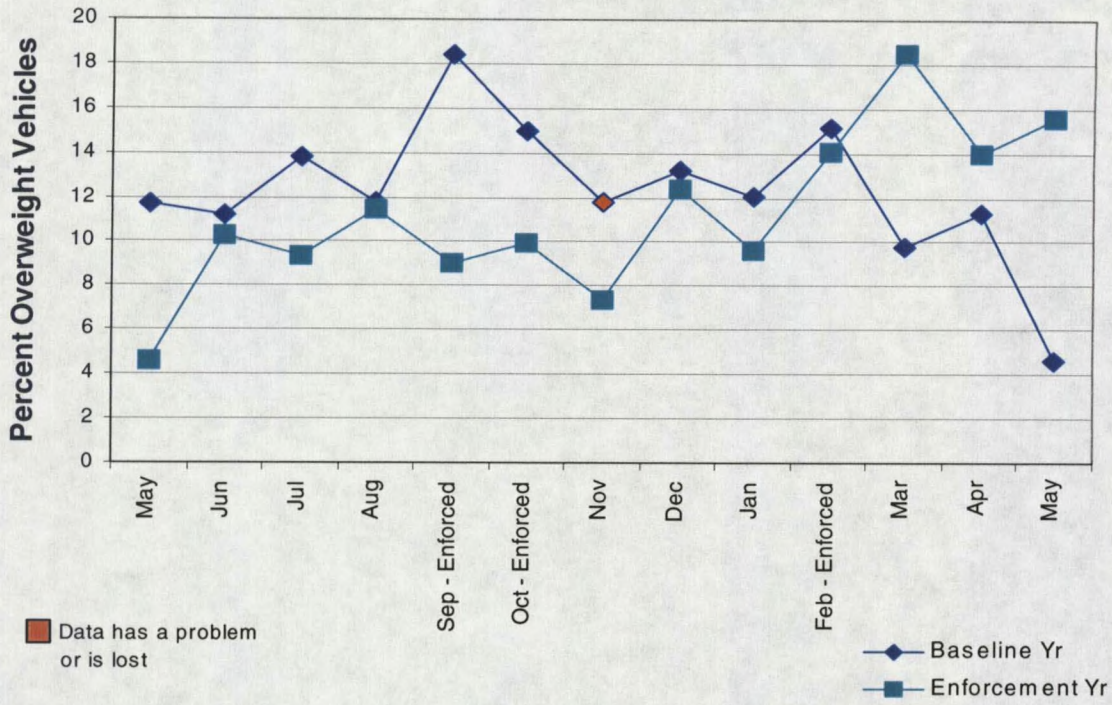


Figure 9. Percent Overweight Commercial Vehicles by Month at the **Decker** STARS Site, Baseline and Focused Enforcement Years.

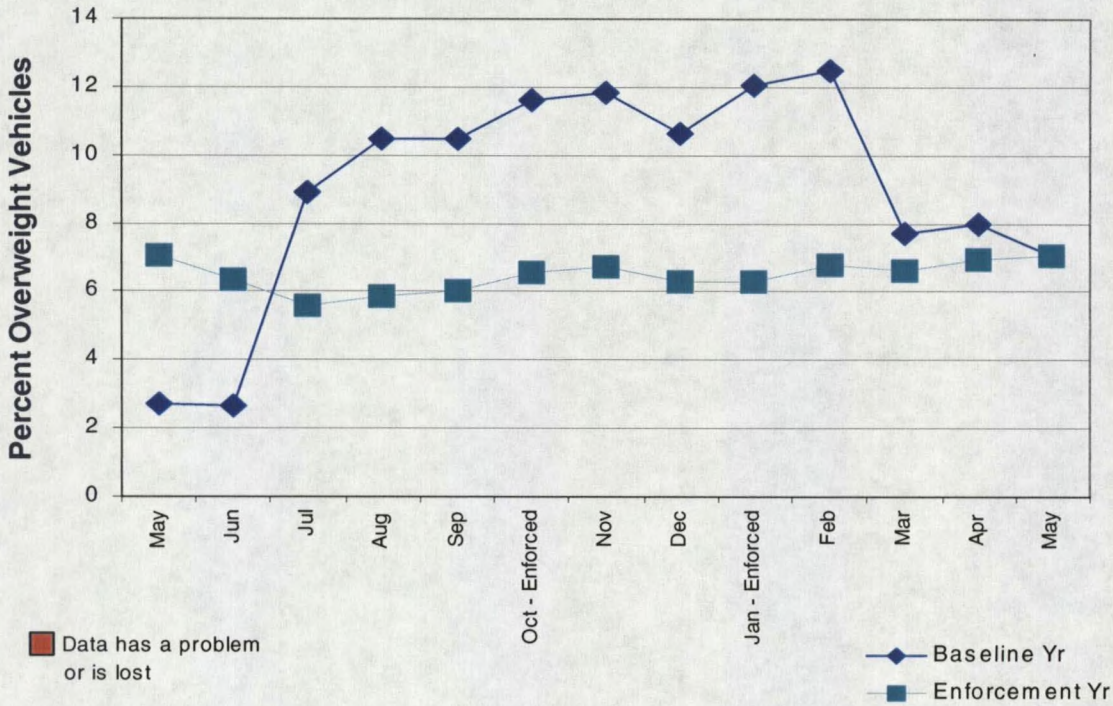


Figure 10. Percent Overweight Commercial Vehicles by Month at the **Manhattan** STARS Site, Baseline and Focused Enforcement Years.

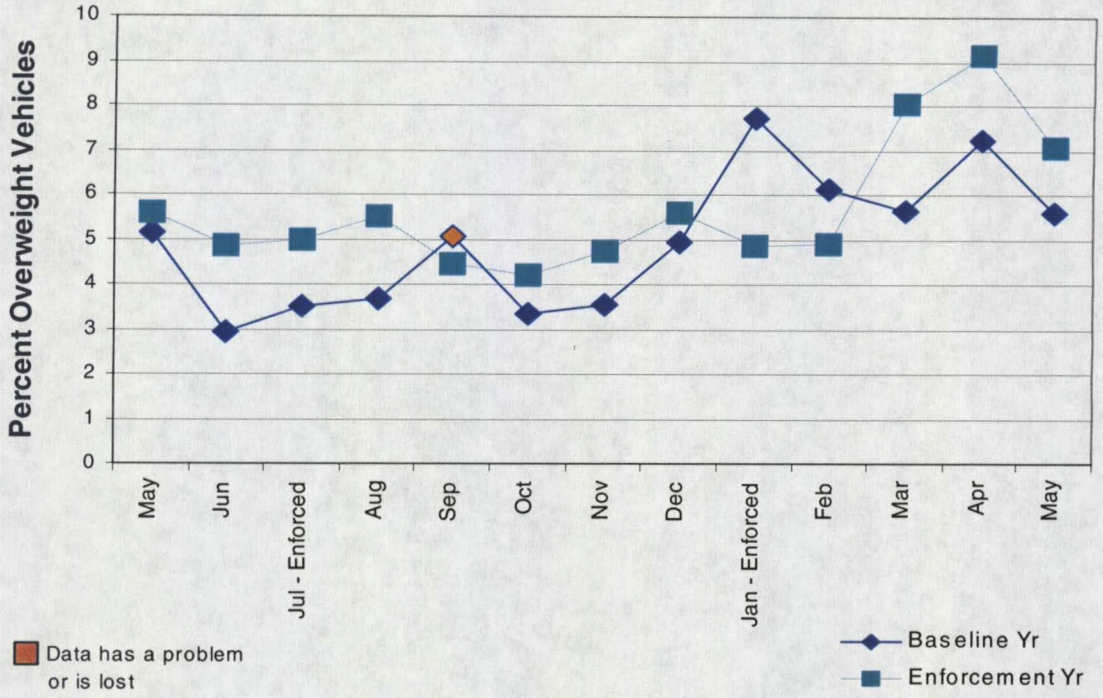


Figure 11. Percent Overweight Commercial Vehicles by Month at the **Arlee** STARS Site, Baseline and Focused Enforcement Years.

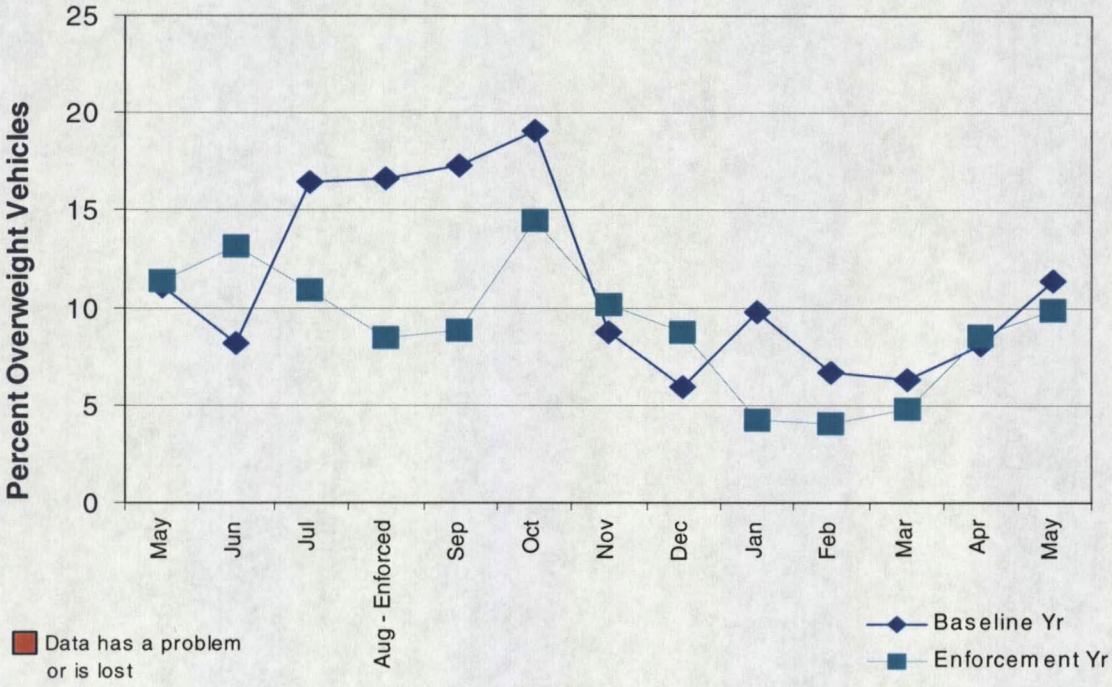


Figure 12. Percent Overweight Commercial Vehicles by Month at the **Miles City East** STARS Site, Baseline and Focused Enforcement Years.

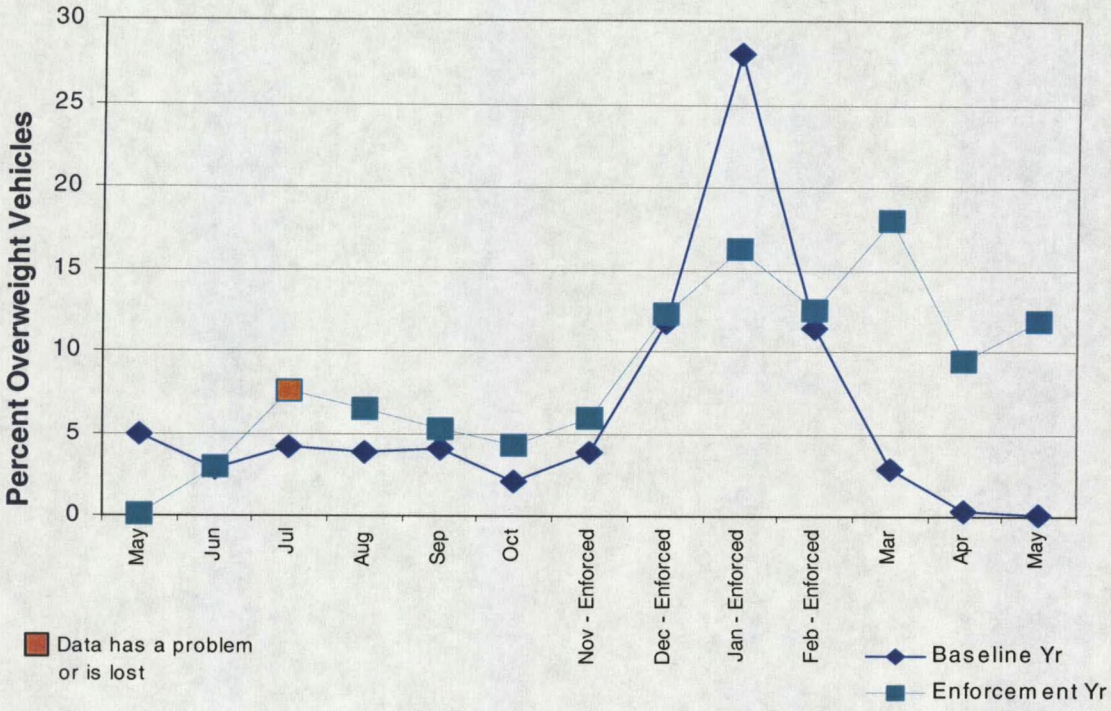


Figure 13. Percent Overweight Commercial Vehicles by Month at the **Ulm** STARS Site, Baseline and Focused Enforcement Years.

In some cases the percent of overweight vehicles in the traffic stream during the enforcement year is lower than that of the baseline year, but it also often higher than that of the baseline year. STARS may have had a positive effect at some sites that were not the focus of enforcement due to residual geographic effects, particularly on commercial vehicle travel routes that encompass multiple STARS sites.

Pavement Impacts

The impact of STARS focused enforcement on the pavement infrastructure was evaluated using the change in total ESALs at each site between the baseline and

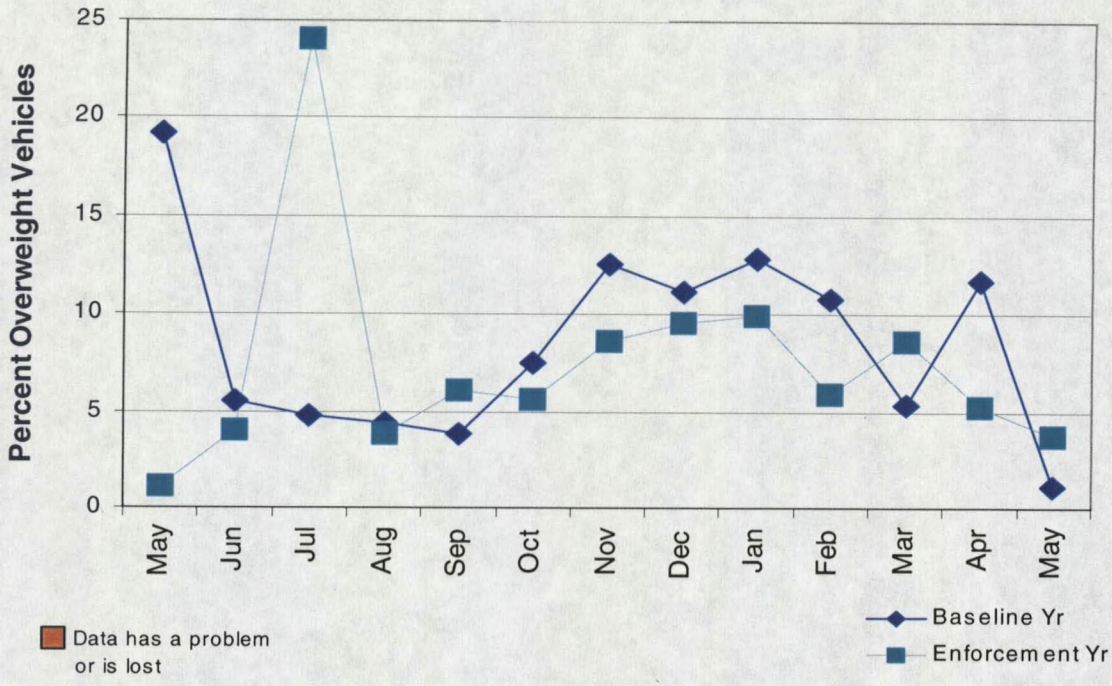


Figure 14. Percent Overweight Commercial Vehicles by Month at the **Galen** STARS Site, Baseline and Focused Enforcement Years.

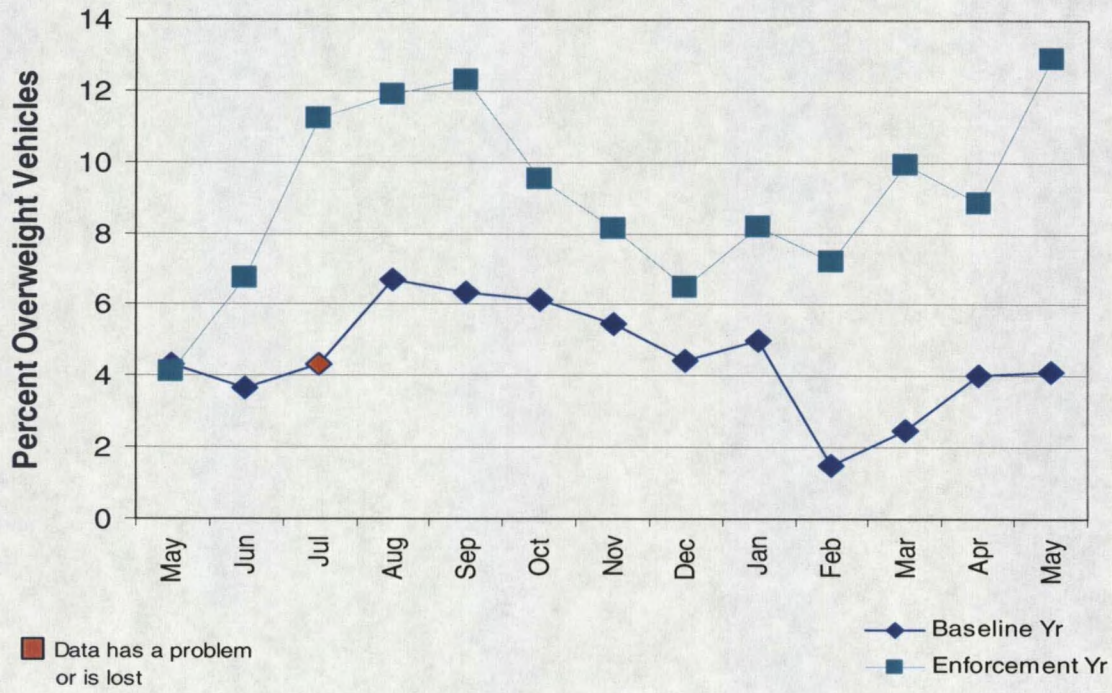


Figure 15. Percent Overweight Commercial Vehicles by Month at the **Broadview** STARS Site, Baseline and Focused Enforcement Years.

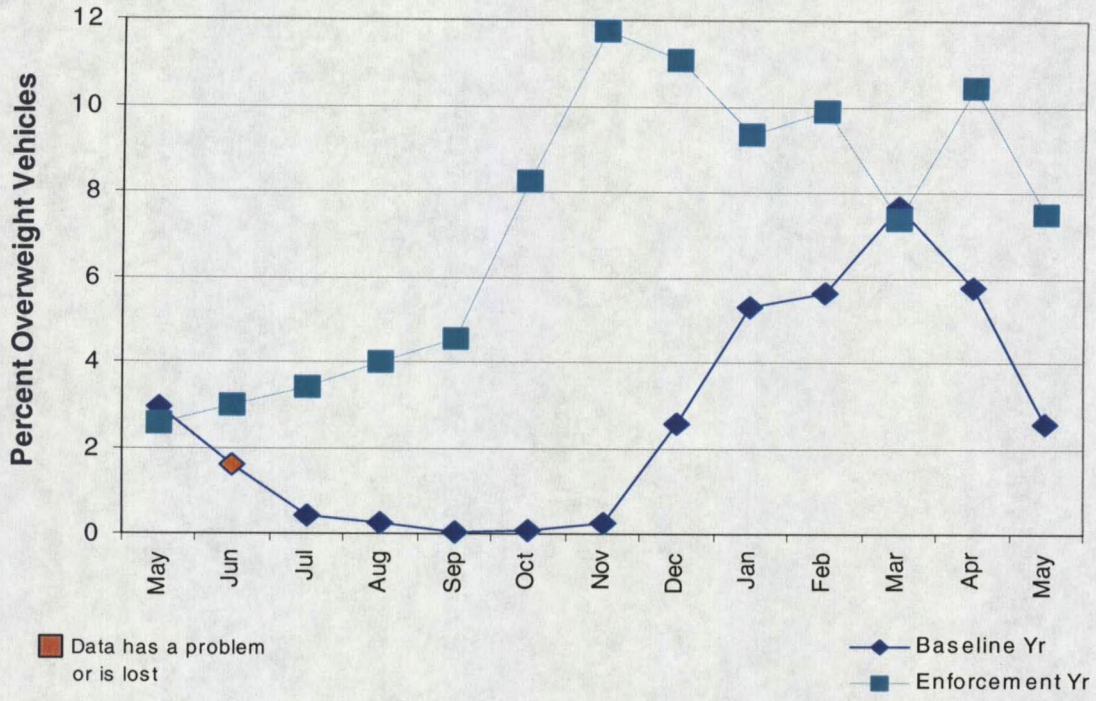


Figure 16. Percent Overweight Commercial Vehicles by Month at the **Fort Benton** STARS Site, Baseline and Focused Enforcement Years.

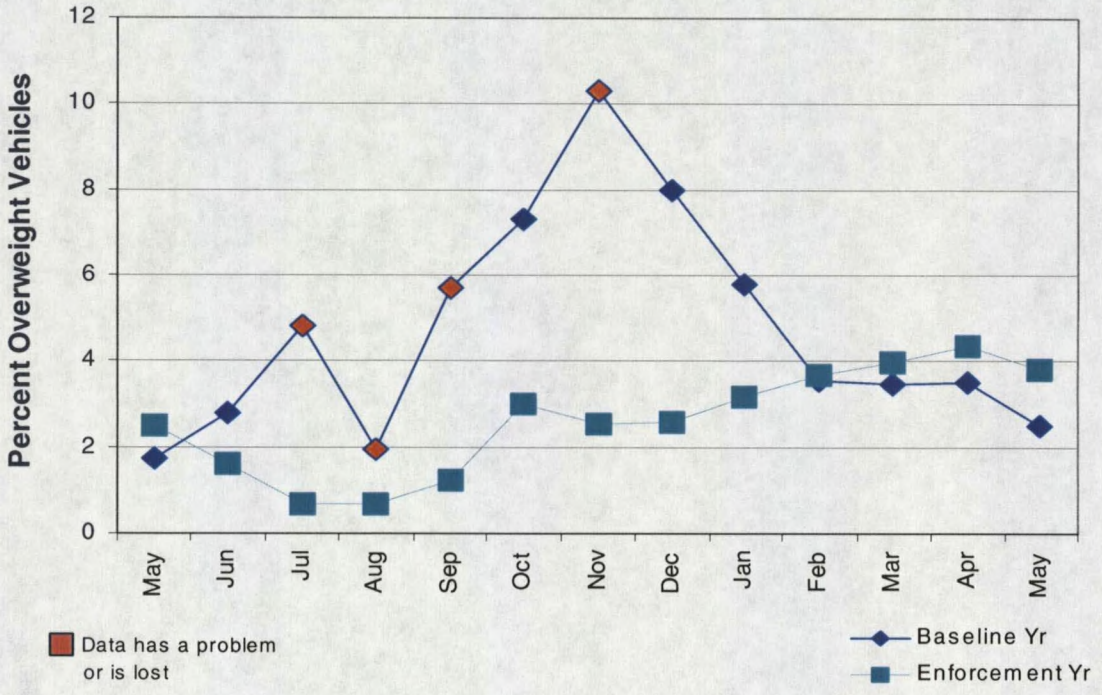


Figure 17. Percent Overweight Commercial Vehicles by Month at the **Havre East** STARS Site, Baseline and Focused Enforcement Years.

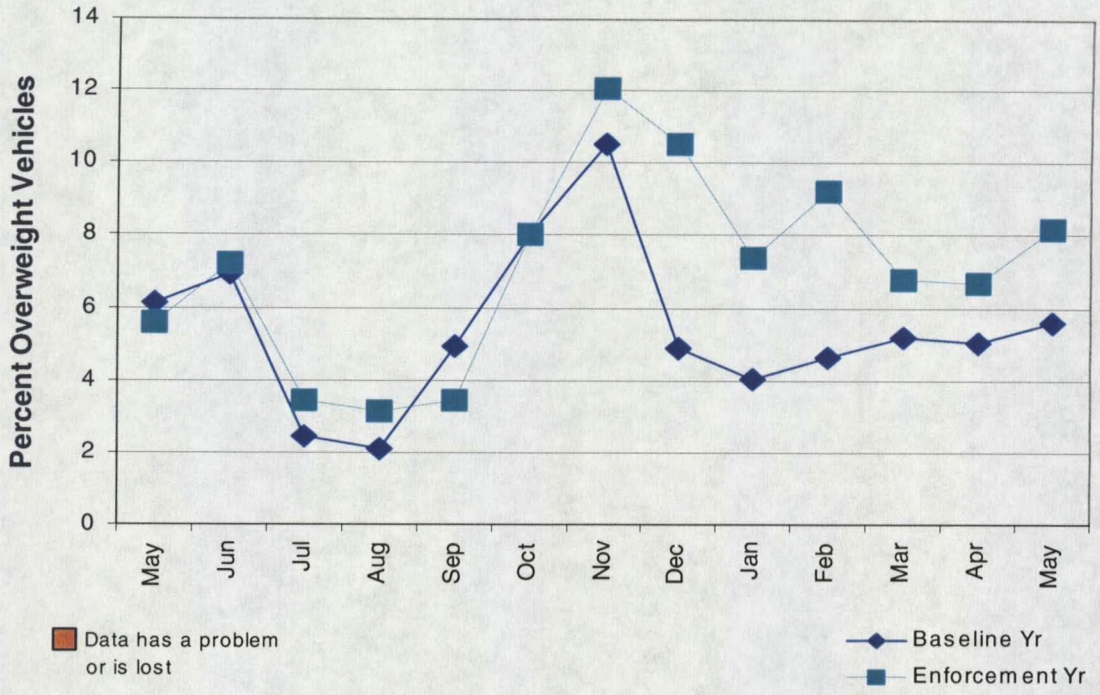


Figure 18. Percent Overweight Commercial Vehicles by Month at the **Paradise** STARS Site, Baseline and Focused Enforcement Years.

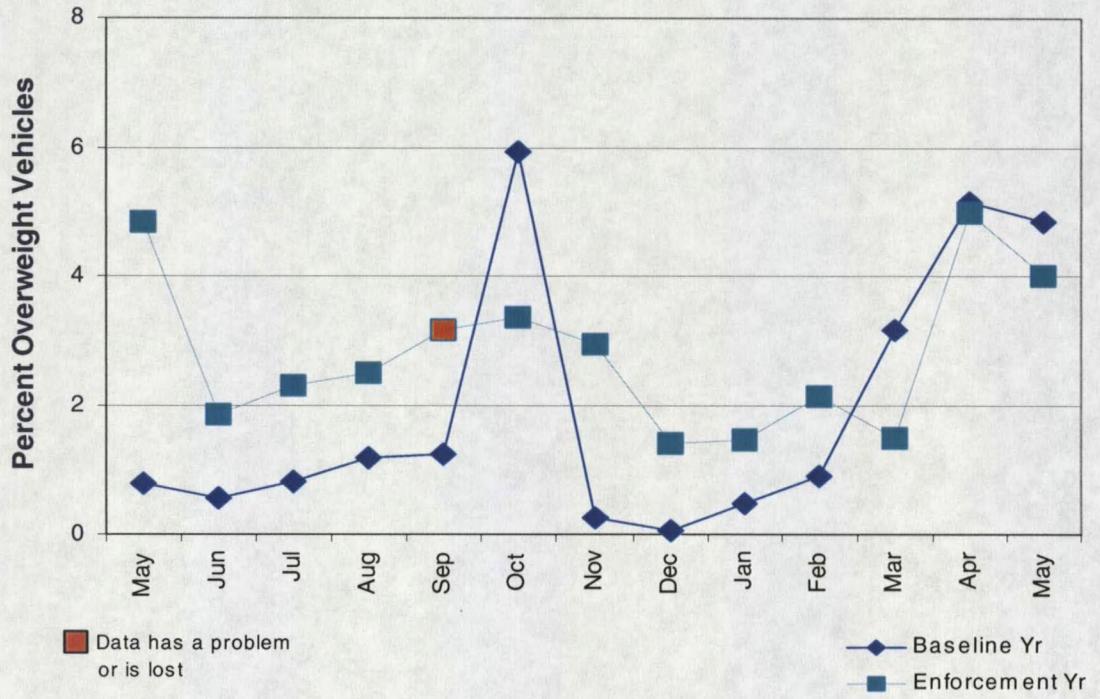


Figure 19. Percent Overweight Commercial Vehicles by Month at the **Culbertson** STARS Site, Baseline and Focused Enforcement Years.

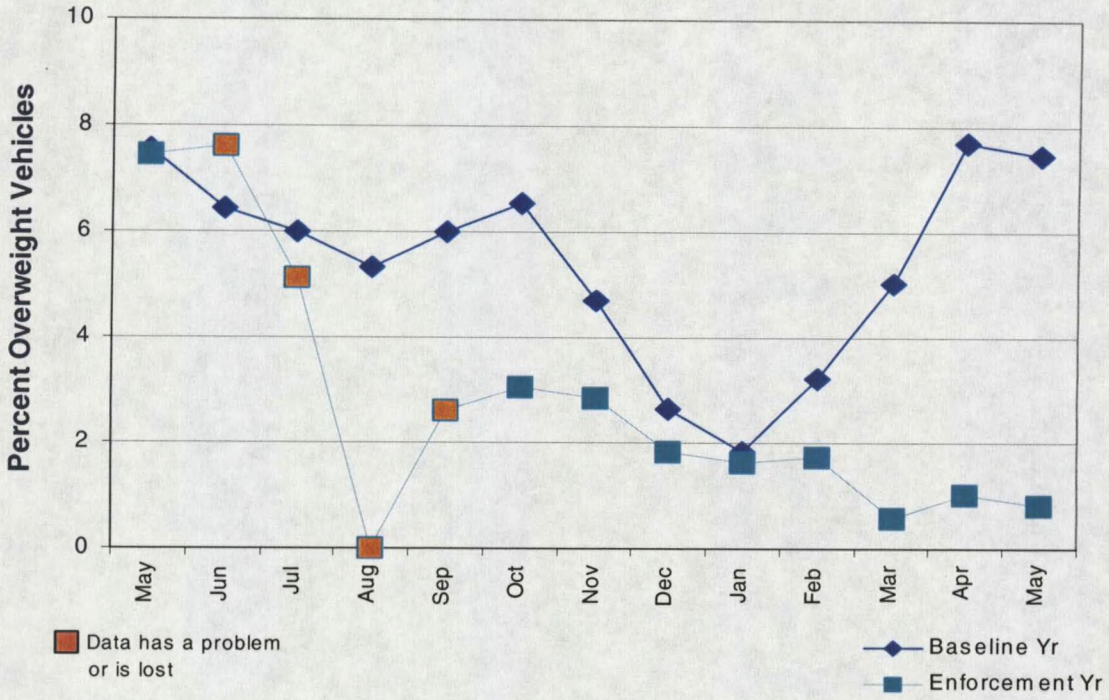


Figure 20. Percent Overweight Commercial Vehicles by Month at the **Lima** STARS Site, Baseline and Focused Enforcement Years.

enforcement years as opposed to the overweight ESALs that were used in selecting the sites for focused enforcement. This change in metric accounts for a potential increase in truck traffic during the enforcement year (to accommodate lighter, legal loads, more trucks may be used to move the same volume of commodities). The total ESAL calculations were performed using data from load spectrum reports from each STARS site, instead of data obtained directly from the MEARS reports. Pavement impacts are similarly considered by level of enforcement activity; sites with more than six months, one to six months and without any focused enforcement.

STARS Sites With More Than Six Months of Focused Enforcement. The four STARS sites with seven or more months of focused enforcement clearly show the most dramatic reductions in pavement damage when compared to all other STARS sites (see

Figures 21 through 24). Similar to the percent of overweight vehicles in the traffic stream, an unexpected increase in pavement damage is seen in the months of March and April at several sites. Otherwise, those months with the most significant decreases in pavement damage generally correspond to months of focused enforcement.

Once again, the trend at Ryegate is worth noting (see Figure 23). A decrease in pavement damage occurs during the enforcement month of September followed by the opposite result in the non-enforced month of October. The following months of resumed enforcement result in another dramatic decrease in pavement damage.

At the Stanford site (see Figure 24), the non-enforced months of December and January show a potential residual effect of the STARS program; there is a continued decrease in pavement damage following several months of focused enforcement.

STARS Sites With One to Six Months of Focused Enforcement. Figures 25 through 29 depict the changes in pavement damage associated with STARS sites that had one to six months of focused enforcement. While it again becomes increasingly difficult to see the effect of the STARS program at sites with fewer months of focused enforcement, these months still generally show a decrease in pavement damage.

The desired effects of STARS focused enforcement can be observed during the enforcement month of January at the Arlee Site (Figure 27) and during the enforcement month of August at the Miles City East site (Figure 28). Although the enforced month of July at the Arlee site corresponds to an increase in pavement damage, it appears as though it has a potential residual affect on the following months at the same site.

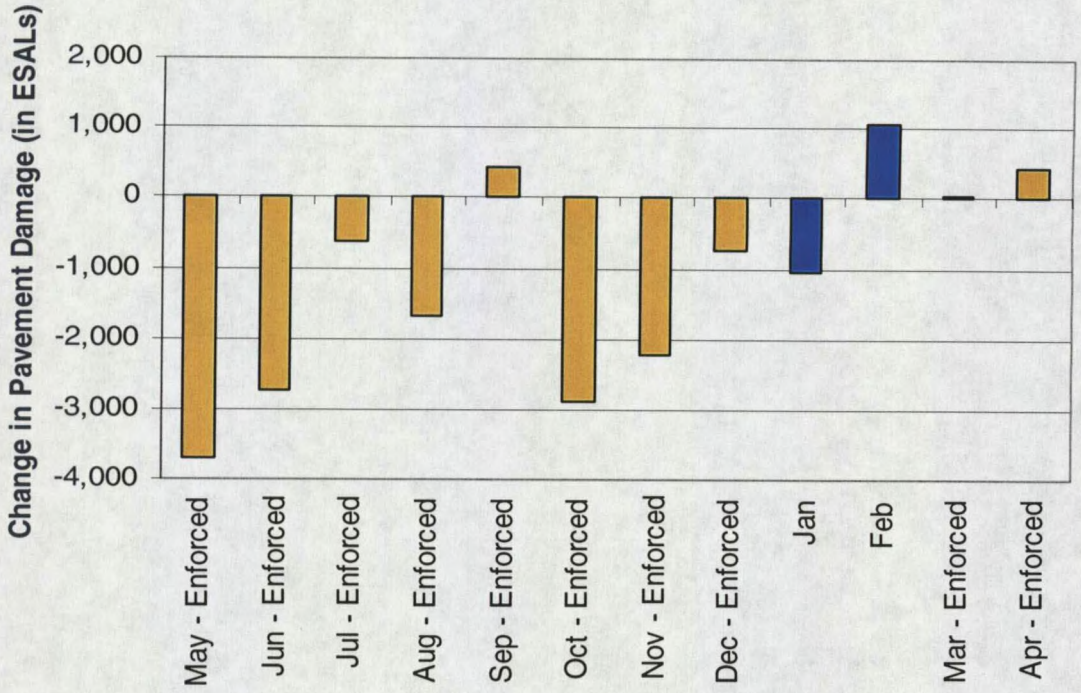


Figure 21. Change in Pavement Damage for the **Townsend** STARS Site, Baseline Year compared to Focused Enforcement Year.

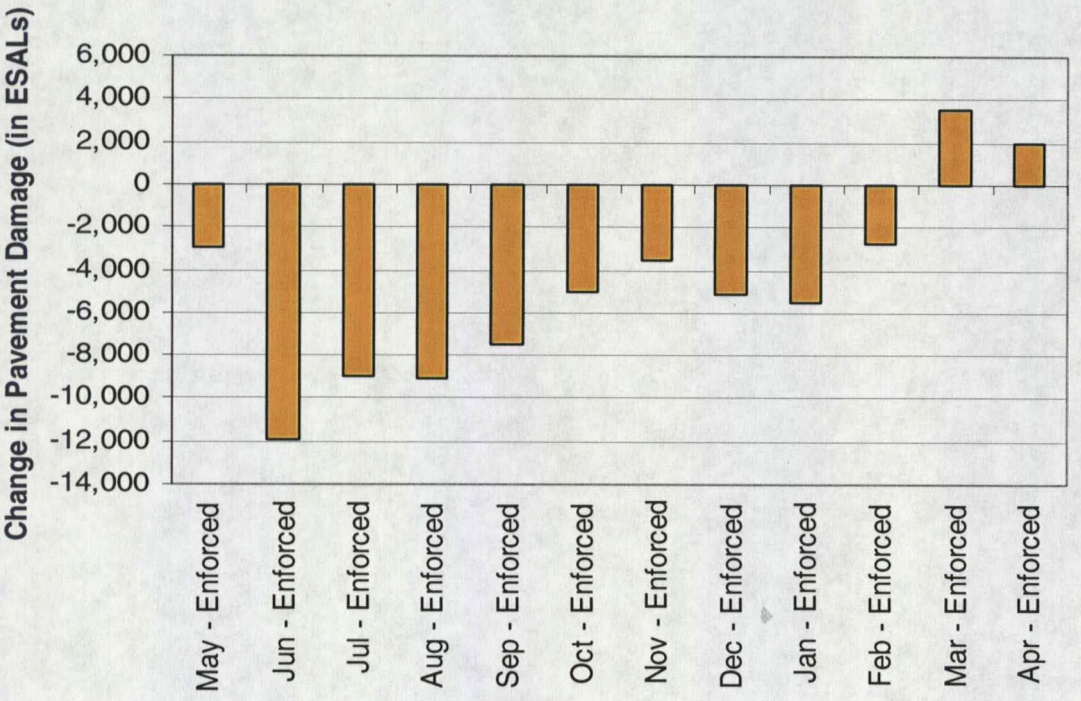


Figure 22. Change in Pavement Damage for the **Four Corners/Gallatin** STARS Site, Baseline Year compared to Focused Enforcement Year.

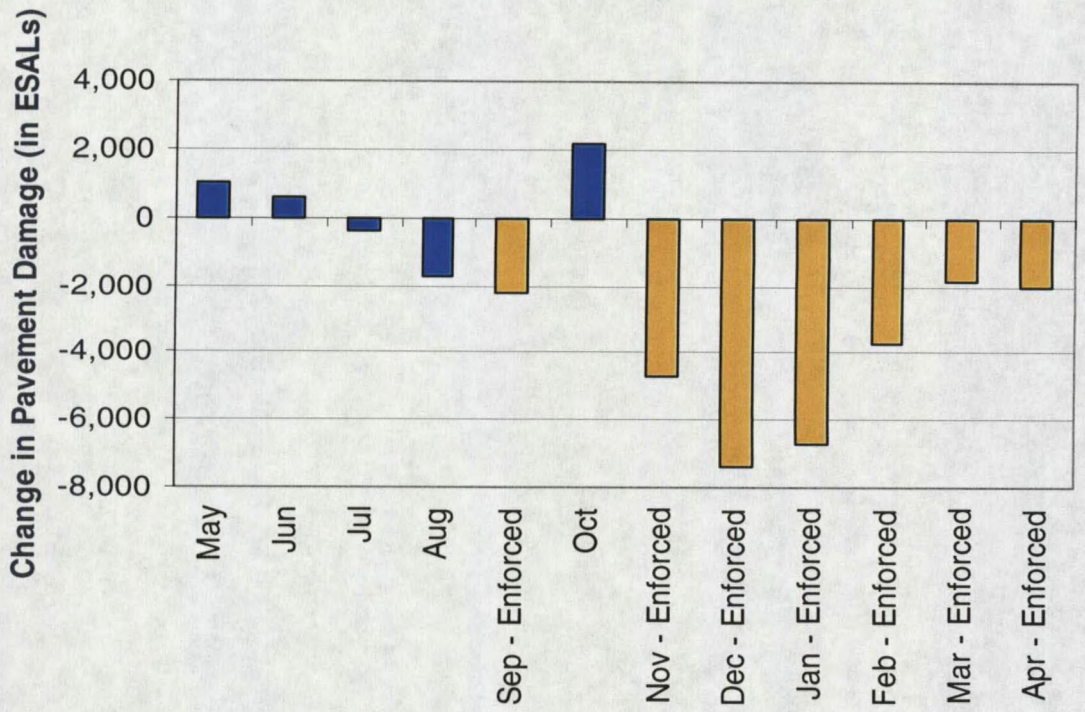


Figure 23. Change in Pavement Damage for the **Ryegate** STARS Site, Baseline Year compared to Focused Enforcement Year.

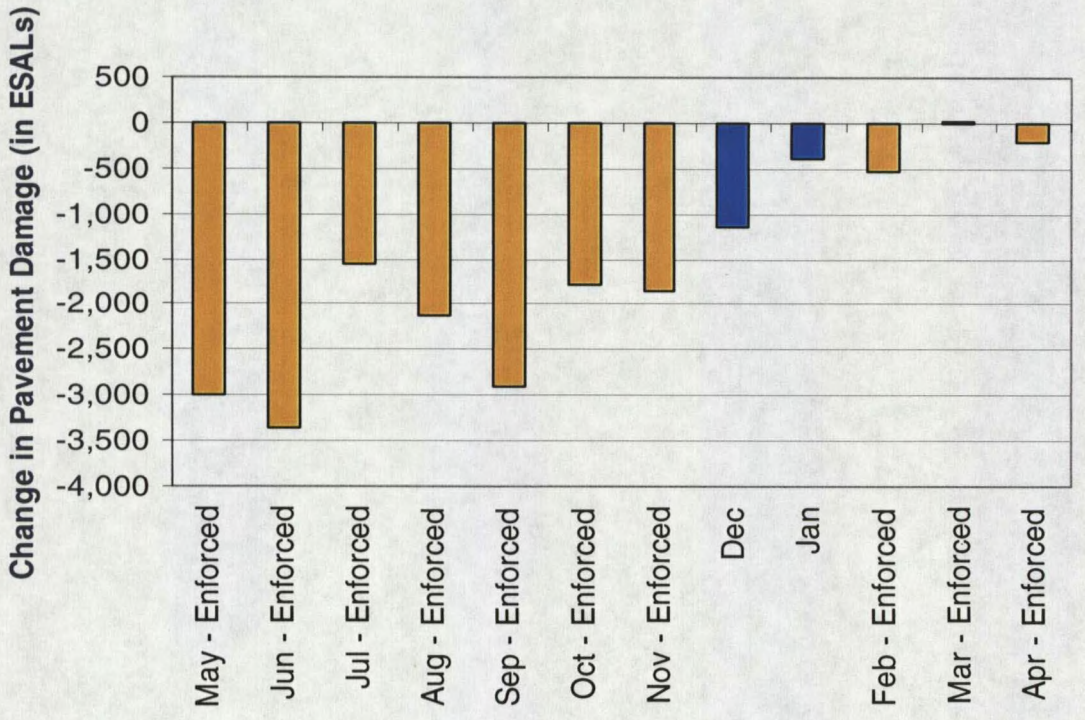


Figure 24. Change in Pavement Damage for the **Stanford** STARS Site, Baseline Year compared to Focused Enforcement Year.

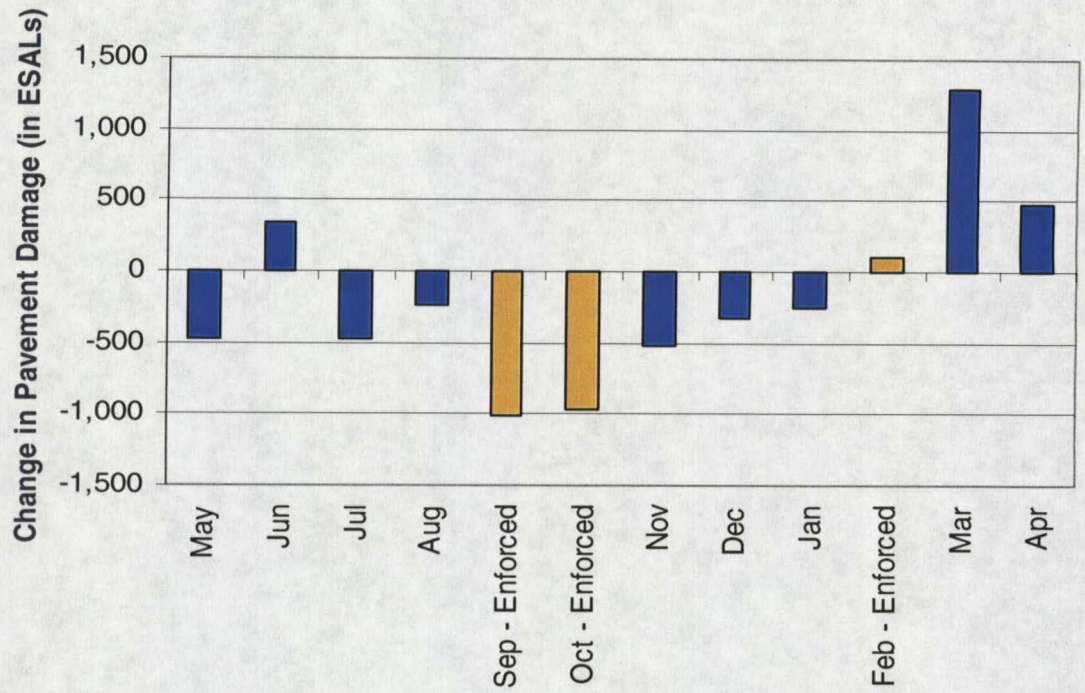


Figure 25. Change in Pavement Damage for the **Decker** STARS Site, Baseline Year compared to Focused Enforcement Year.

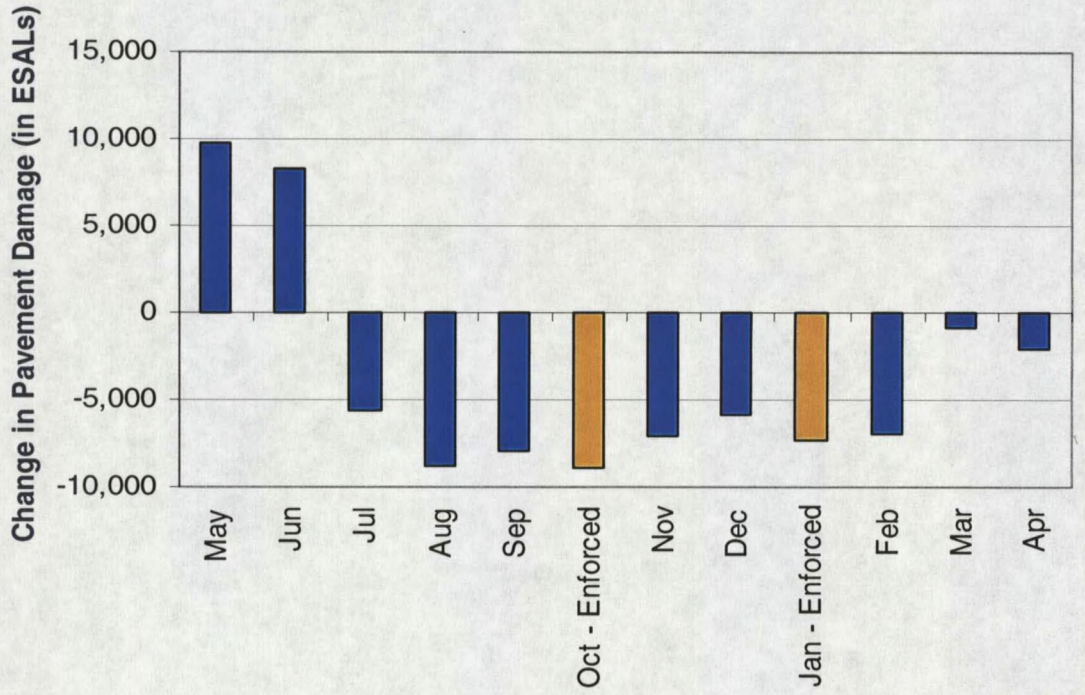


Figure 26. Change in Pavement Damage for the **Manhattan** STARS Site, Baseline Year compared to Focused Enforcement Year.

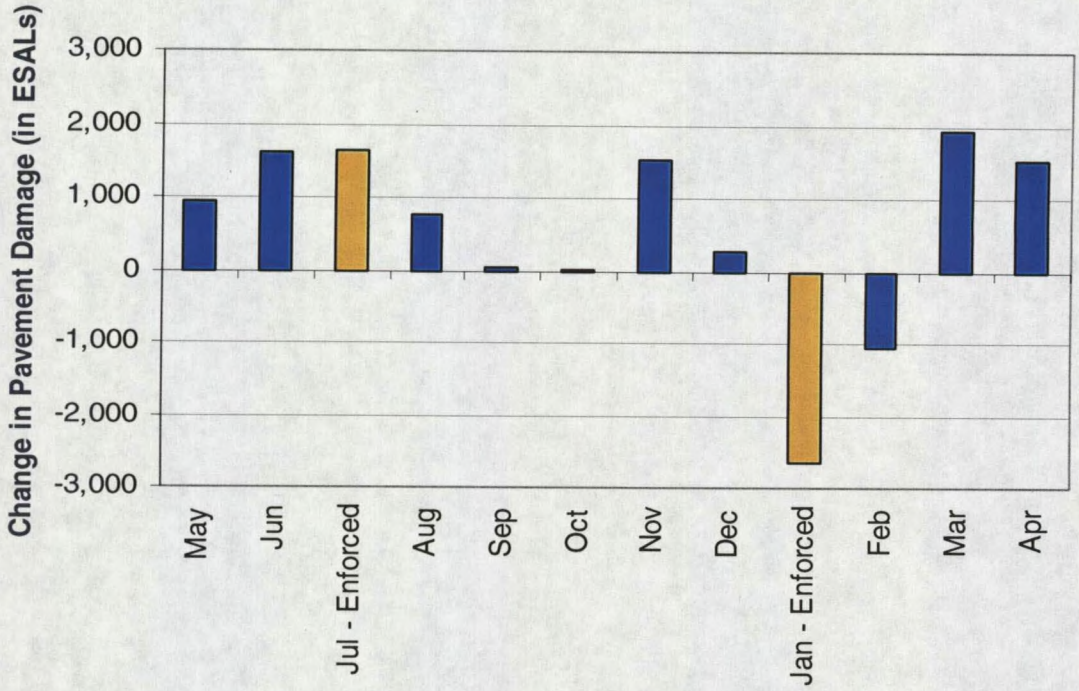


Figure 27. Change in Pavement Damage for the **Arlee** STARS Site, Baseline Year compared to Focused Enforcement Year.

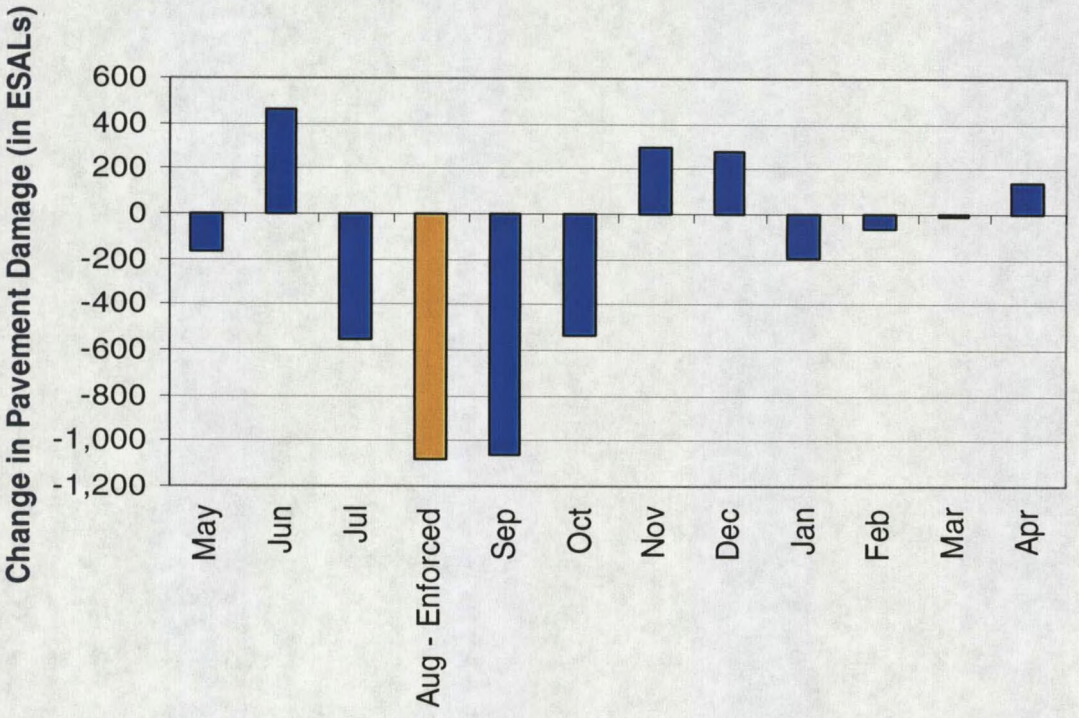


Figure 28. Change in Pavement Damage for the **Miles City East** STARS Site, Baseline Year compared to Focused Enforcement Year.

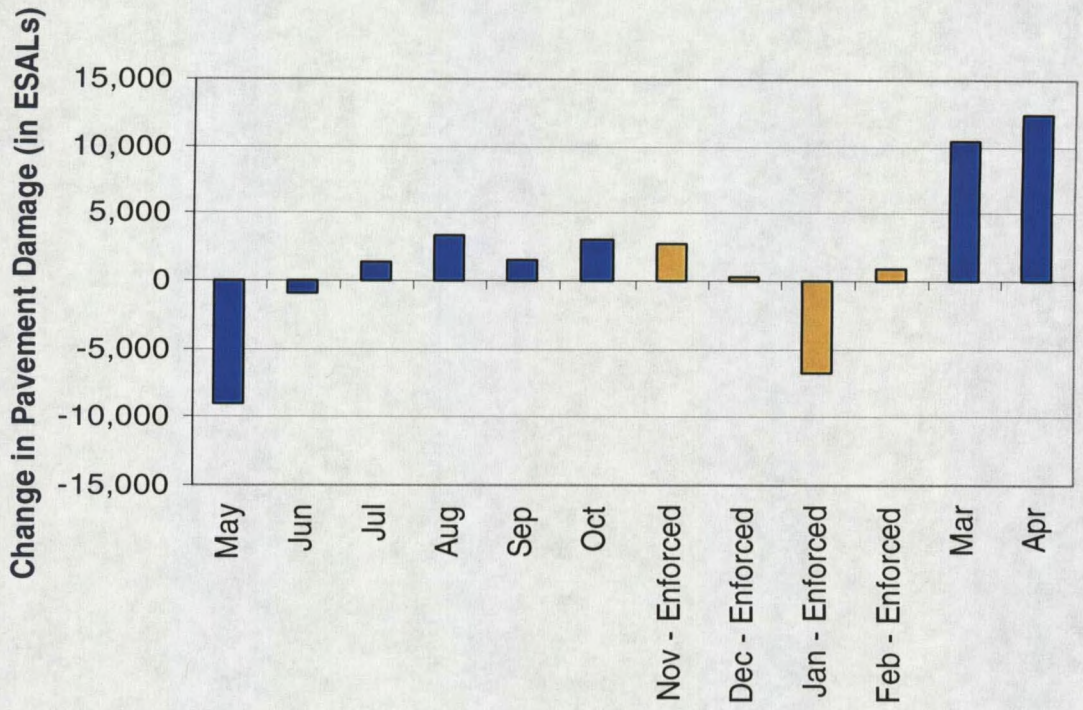


Figure 29. Change in Pavement Damage for the **Ulm** STARS Site, Baseline Year compared to Focused Enforcement Year.

STARS Sites Not Selected for Focused Enforcement. Figures 30 through 36 depict those sites that did not warrant focused enforcement during the investigation period. It is difficult to make a determination on the effect of STARS at these sites, but it is expected that an increase in pavement damage would occur since enforcement either remains at the same level or decreases. Broadview and Fort Benton (see Figures 31 and 32) show a considerable increase in pavement damage between the baseline year and the enforcement year over all twelve months. While it could be concluded that this is due to the fact that there were not any focused enforcement efforts at these sites, it is possible that this is due to enforcement efforts being directed away from these sites to increase enforcement at sites where more pavement damage is taking place.

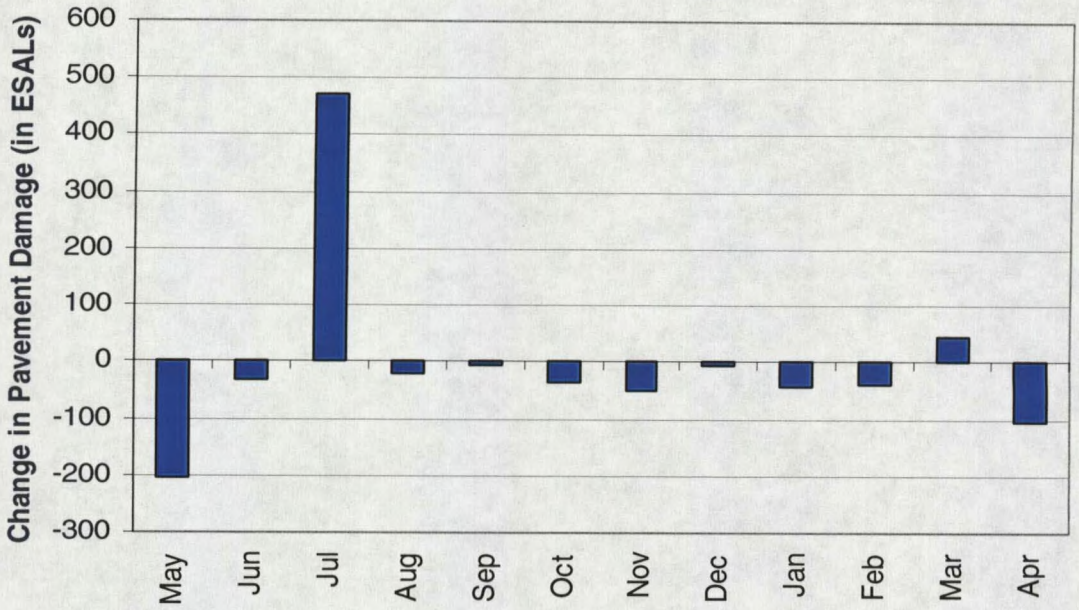


Figure 30. Change in Pavement Damage for the **Galen** STARS Site, Baseline Year compared to Focused Enforcement Year.

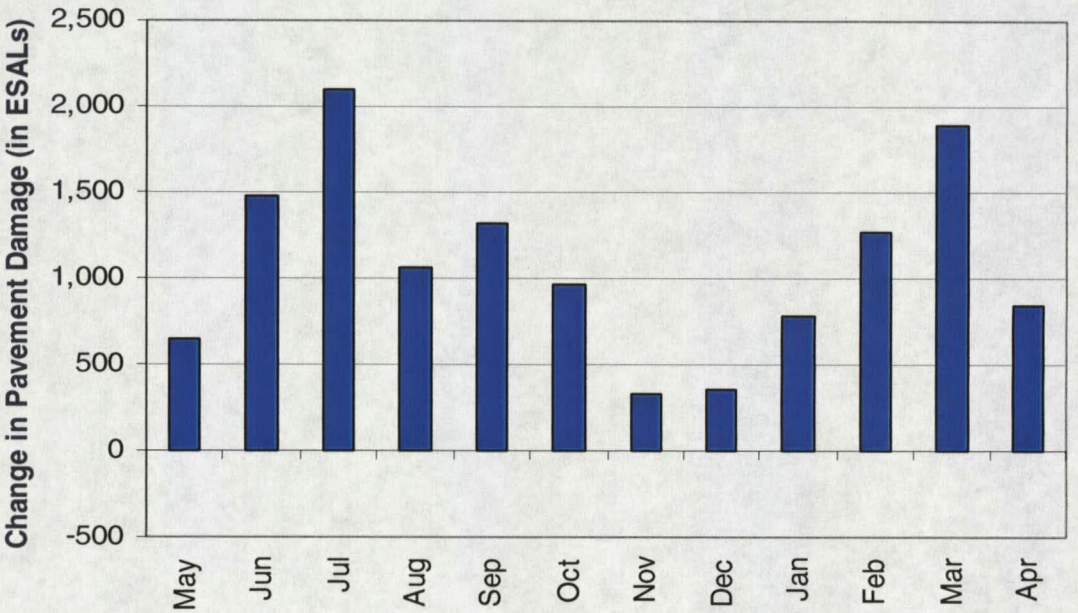


Figure 31. Change in Pavement Damage for the **Broadview** STARS Site, Baseline Year compared to Focused Enforcement Year.

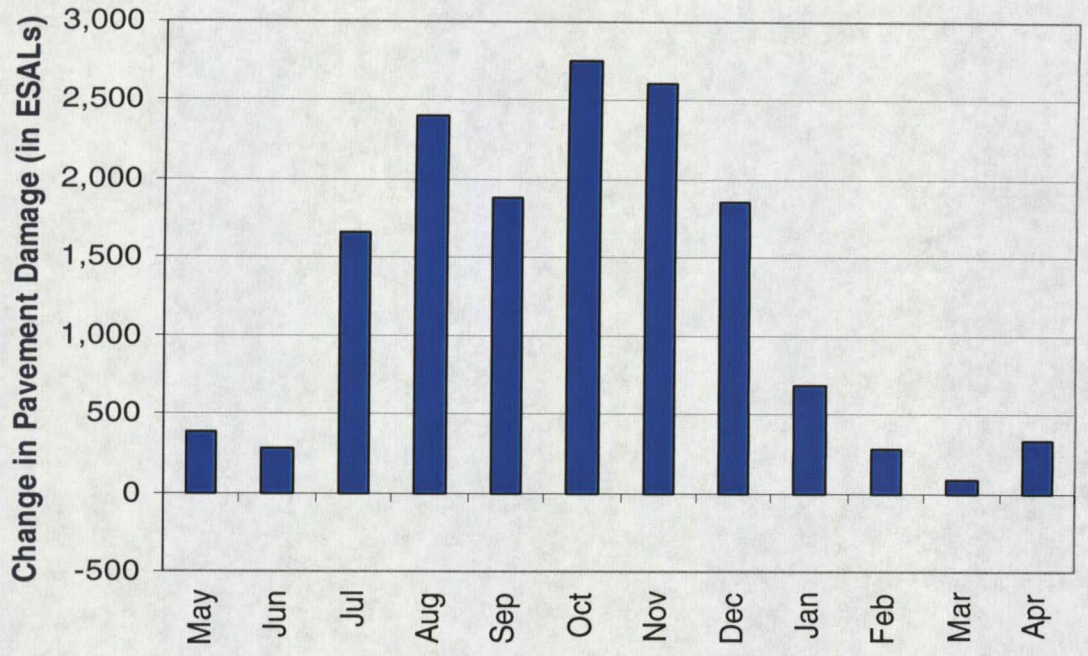


Figure 32. Change in Pavement Damage for the **Fort Benton** STARS Site, Baseline Year compared to Focused Enforcement Year.

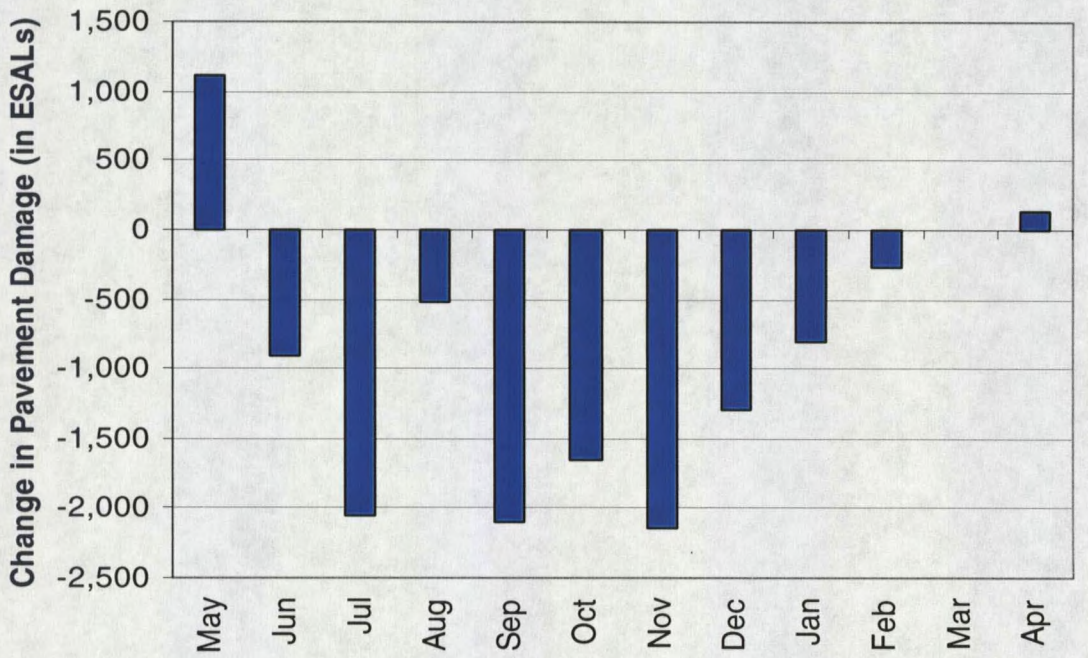


Figure 33. Change in Pavement Damage for the **Havre East** STARS Site, Baseline Year compared to Focused Enforcement Year.

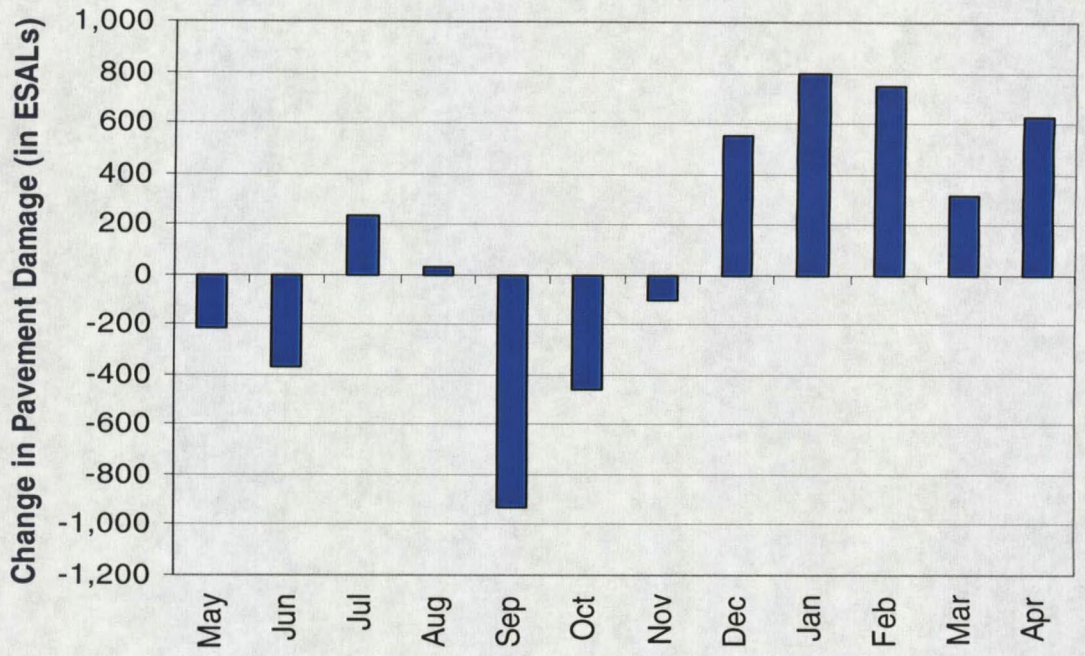


Figure 34. Change in Pavement Damage for the **Paradise** STARS Site, Baseline Year compared to Focused Enforcement Year.

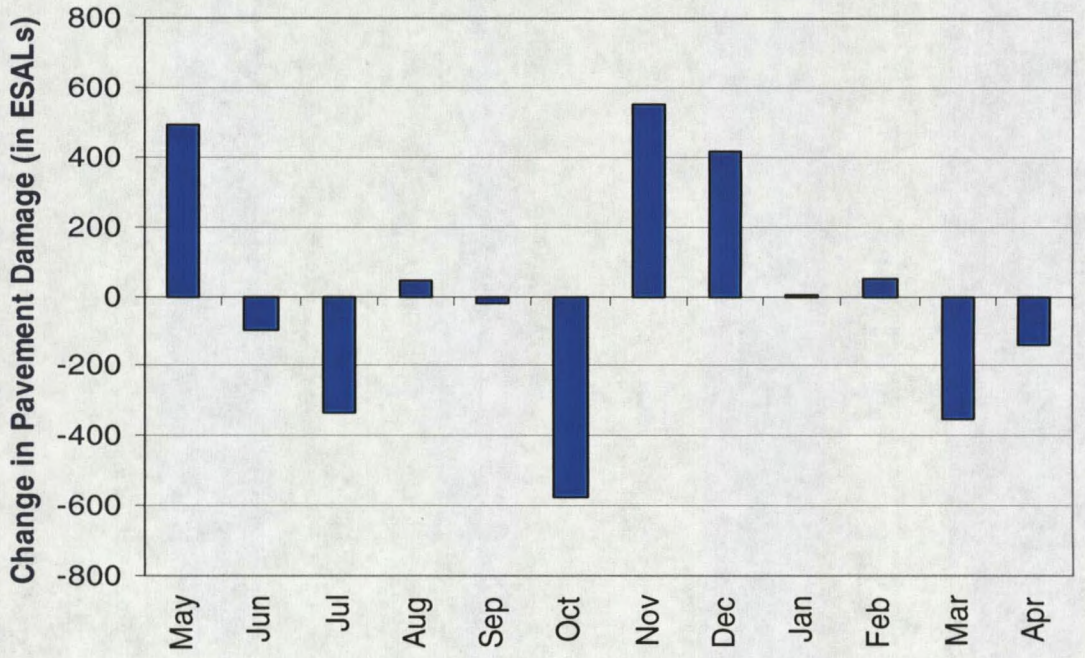


Figure 35. Change in Pavement Damage for the **Culbertson** STARS Site, Baseline Year compared to Focused Enforcement Year.

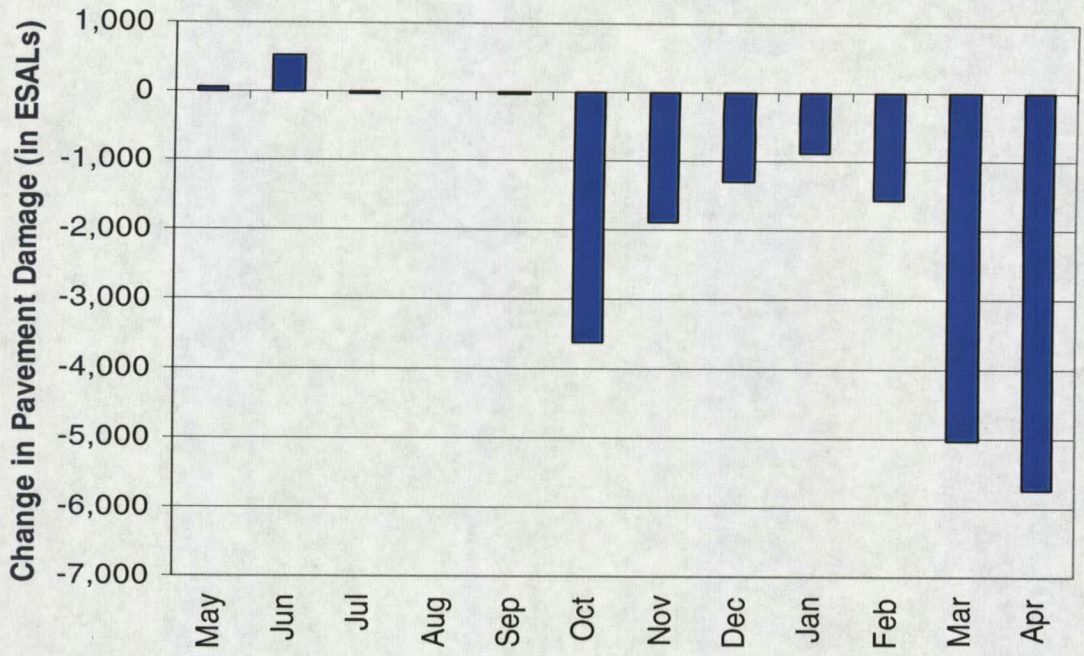


Figure 36. Change in Pavement Damage for the **Lima** STARS Site, Baseline Year compared to Focused Enforcement Year.

Changes in Vehicle Weight Distributions

As mentioned previously, STARS focused enforcement may result in an increase in compliant truck traffic volumes to move the same volume of freight. To further investigate this supposition, frequency distributions by weight for targeted truck configurations were compared for months with and without focused enforcement. Frequency distributions by weight for Class 9 vehicles (5-axle tractor, semi-trailers) are presented in Figure 37 for a typical site for a month with and without focused enforcement. These distributions clearly show a shift to fewer overweight vehicles and more weight compliant vehicles during the month of focused enforcement. Similar results were observed at almost all sites across almost all vehicle configurations (both those targeted and not targeted for enforcement).

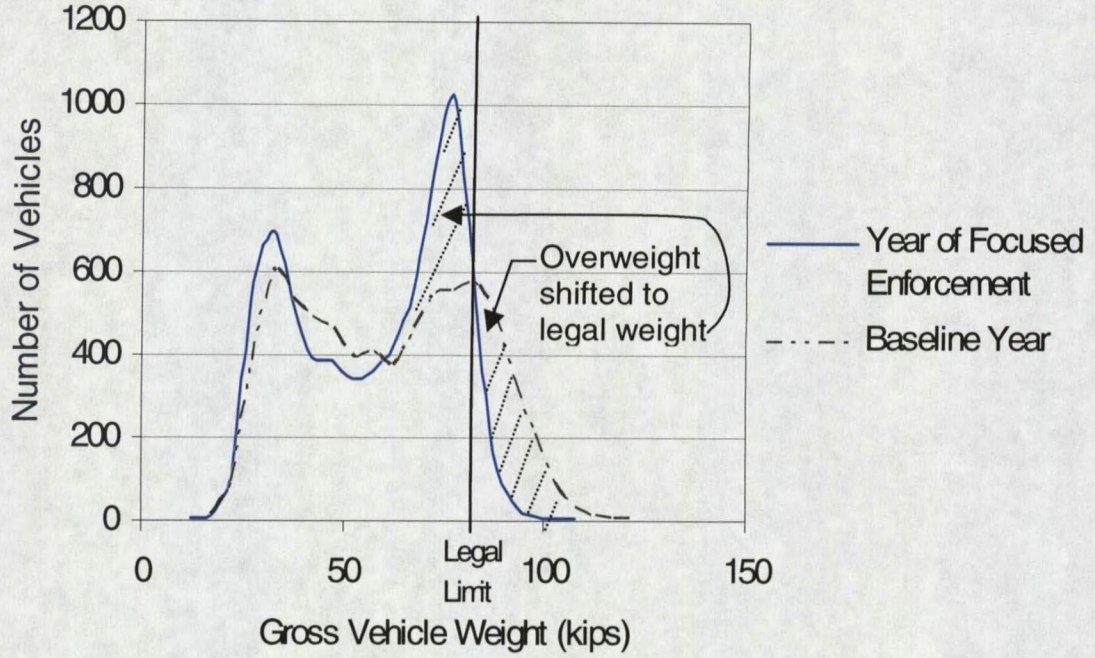


Figure 37. Gross Vehicle Weight Distributions for Class 9 Vehicles at a Typical STARS Site With and Without Focused Enforcement

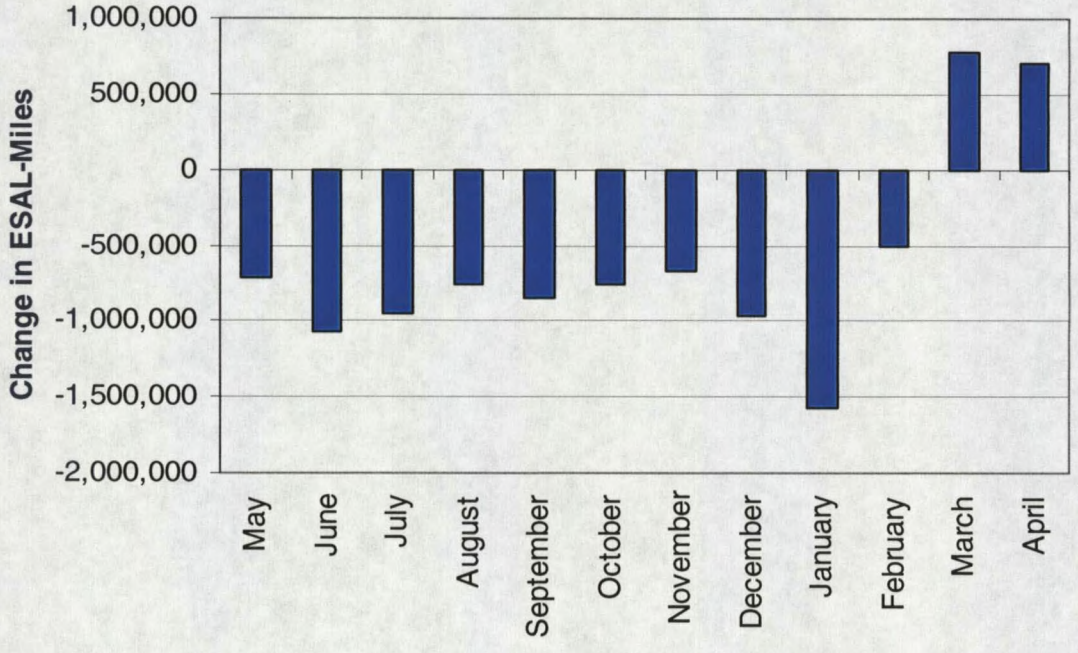


Figure 38. Statewide Change in Pavement Damage for **Class 9** Commercial Vehicles, Baseline Year Compared to Focused Enforcement Year.

Statewide Effects

Statewide effects of the STARS program were evaluated based on a change in ESAL-miles and the cost savings related to this change. ESAL-miles was selected as the measure of effectiveness for statewide effects instead of ESALs to better account for the total infrastructure mileage potentially affected by focused, site-specific enforcement activities. Affected mileage and related costs were determined using the procedure outlined in Chapter 3 Methodology. The statewide effects of STARS were considered on a yearly basis by vehicle configuration, site and month. In addition, the comprehensive effects of focused enforcement were compared to those of non-focused enforcement.

Statewide Change in Pavement Damage and Related Cost Savings by Configuration. The load spectrum reports used for ESAL calculations group axle weights based on vehicle configuration or class. Class 9, 10 and 13 vehicles typically had the highest volumes and the greatest number of ESALs per vehicle and were therefore most commonly selected for focused enforcement. As a result, it is beneficial to look more closely at the change in pavement damage associated with these configurations.

Figures 38 through 43 depict the change in pavement damage and related changes in cost for these three vehicle configurations. Overall, it was observed that focused enforcement efforts had a positive effect on these configurations, as denoted by an obvious decrease in pavement damage and an increase in cost savings. Peculiarly, the opposite effect (an increase in pavement damage and a decrease in savings) is once again seen in the final evaluation months of March and April for all three configurations. As

mentioned in previous sections, this phenomenon could be due to a relaxed emphasis on enforcement toward the end of the program.

When considering total cost savings attributable to STARS (described in more detail later in this Chapter), the savings resulting from focused enforcement of these three configurations alone accounted for over 96 percent of the total cost savings attributable to STARS. This suggests success in focused enforcement efforts, accounting for the majority of the decrease in pavement damage and the increase in related cost savings.

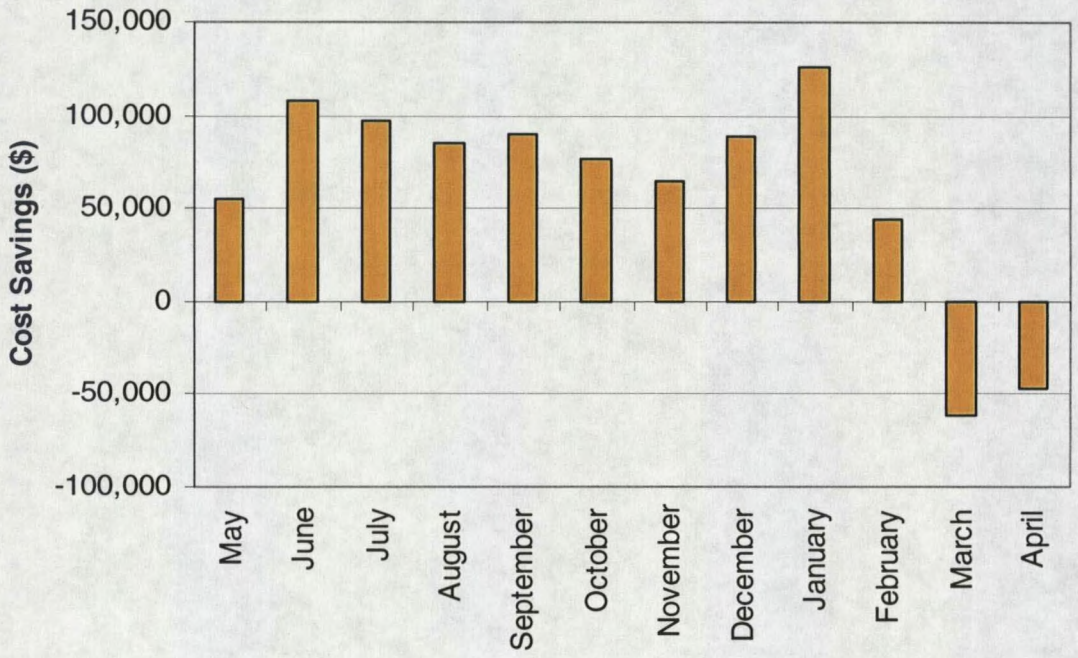


Figure 39. Statewide Cost Savings for **Class 9** Commercial Vehicles, Baseline Year Compared to Focused Enforcement Year.

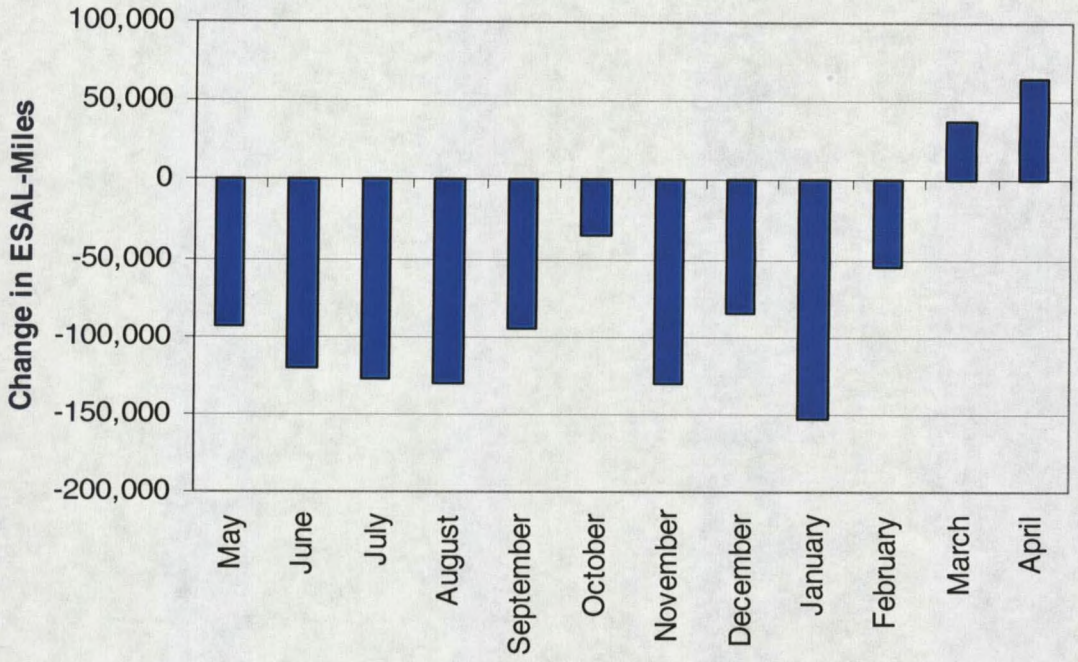


Figure 40. Statewide Change in Pavement Damage for **Class 10** Commercial Vehicles, Baseline Year Compared to Focused Enforcement Year.

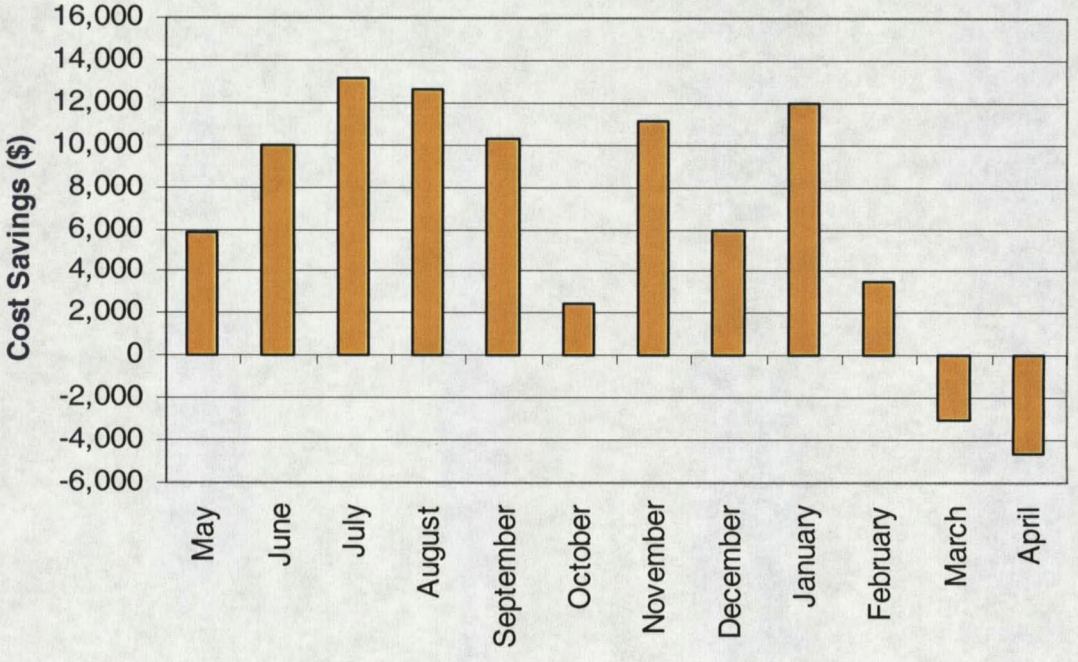


Figure 41. Statewide Cost Savings for **Class 10** Commercial Vehicles, Baseline Year Compare to Focused Enforcement Year.

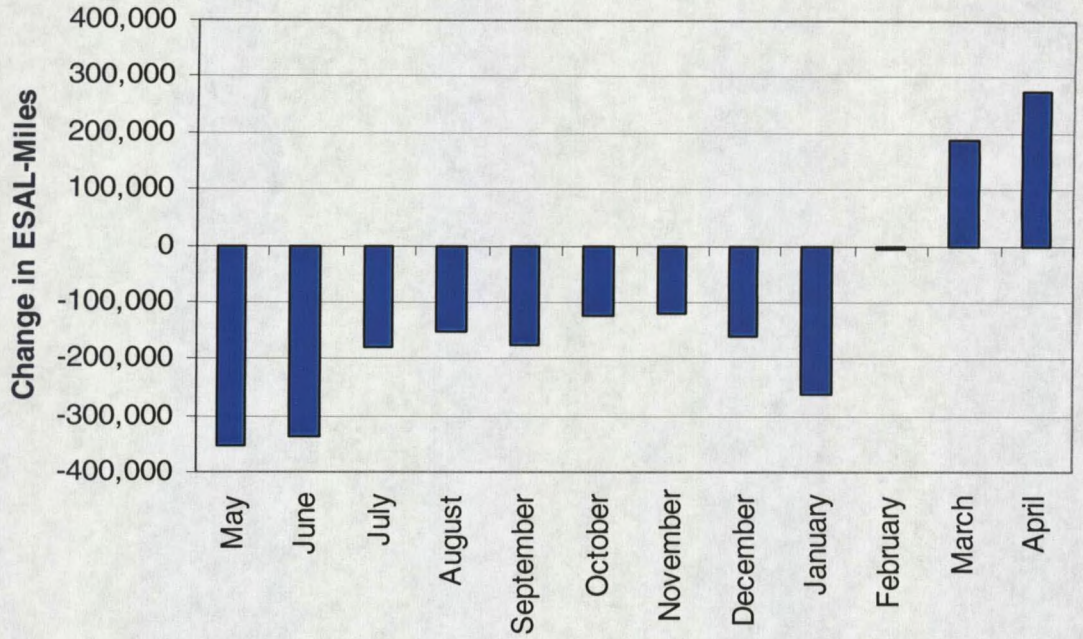


Figure 42. Statewide Change in Pavement Damage for **Class 13** Commercial Vehicles, Baseline Year Compared to Focused Enforcement Year.

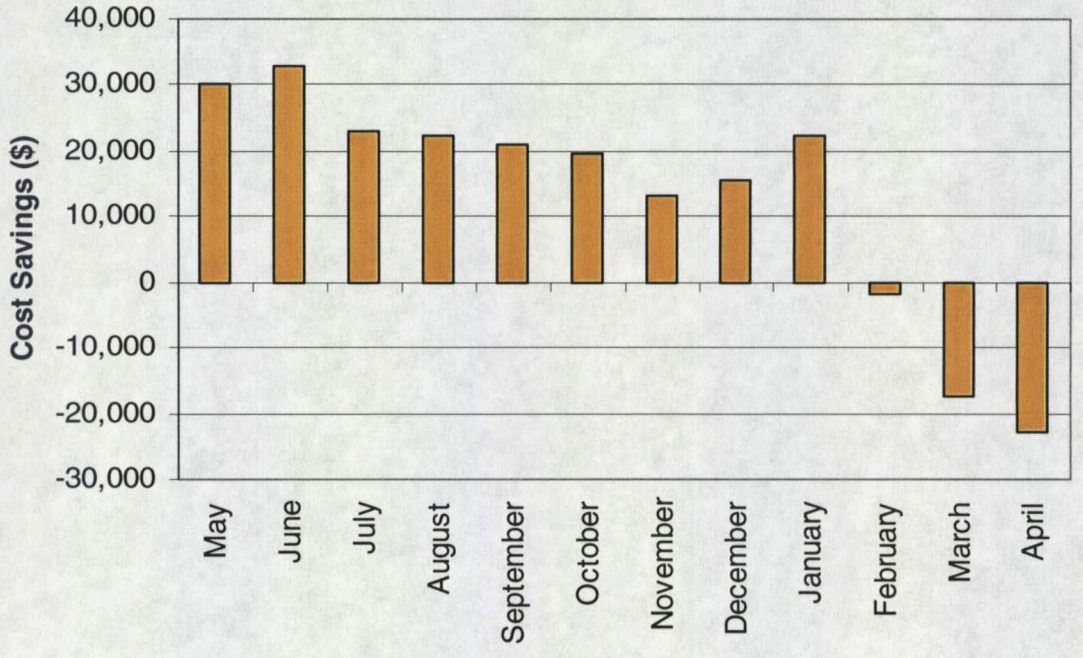


Figure 43. Statewide Cost Savings for **Class 13** Commercial Vehicles, Baseline Year Compared to Focused Enforcement Year.

Yearly Change in Pavement Damage and Related Cost Savings by Site. Figures 44 and 45 summarize the statewide effects of the STARS program by showing the difference in ESAL-miles from the baseline year to the enforcement year depicted by site. Those sites most often selected for focused enforcement (Townsend, Four Corners/Gallatin, Ryegate and Stanford) typically correspond to the greatest reductions in ESAL-miles and the subsequent increases in cost savings. Some of the sites that were not selected for focused enforcement also show a decrease in pavement damage from the baseline year to the enforcement year. As previously stated, confounding factors such as short-term increased construction activities may offer explanation of this phenomenon.

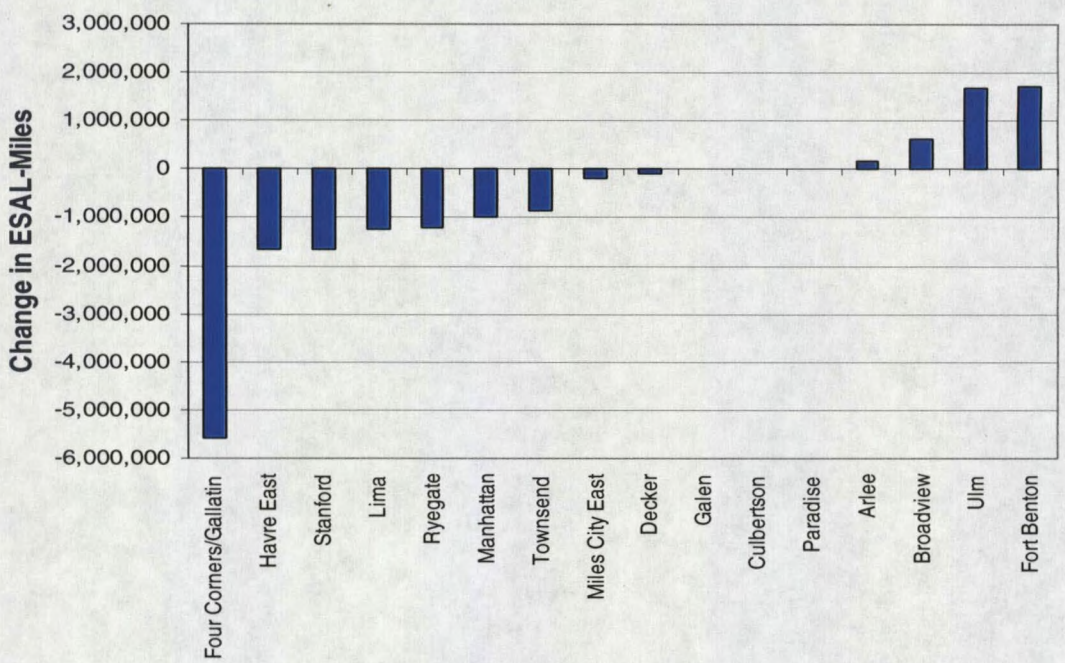


Figure 44. Total Change in Pavement Damage by Site, Baseline Year Compared to Focused Enforcement Year.

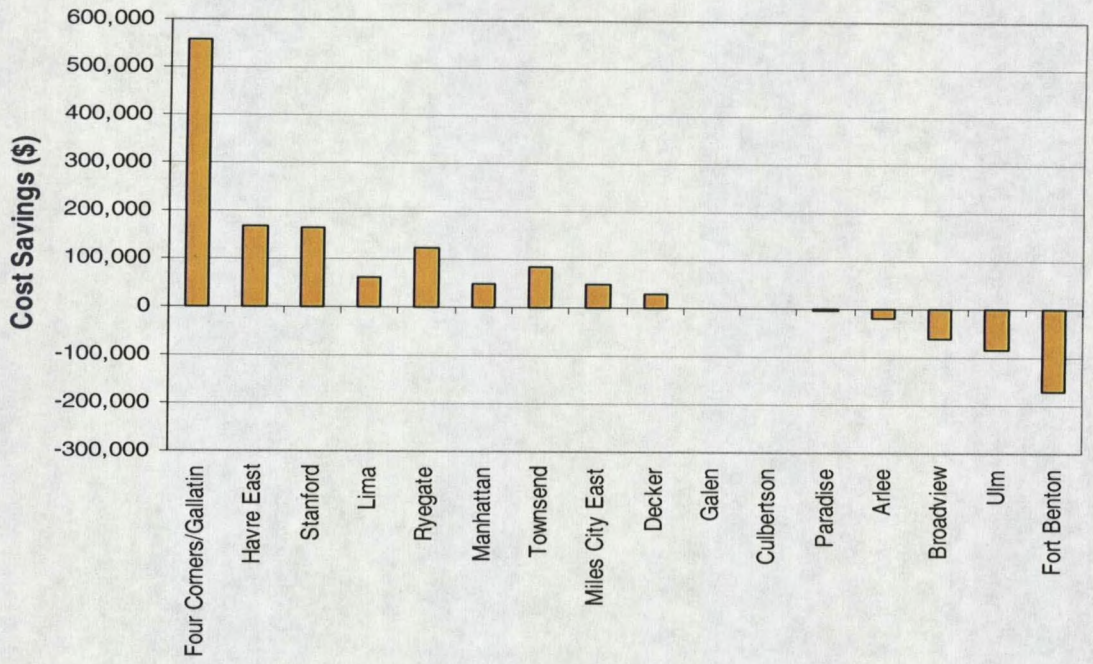


Figure 45. Total Cost Savings by Site, Baseline Year Compared to Focused Enforcement Year.

Statewide Change in Pavement Damage and Related Cost by Month. Figures 46 and 47 summarize the statewide effects of the STARS program by showing the difference in ESAL-miles from the baseline year to the enforcement year by month. A decrease in pavement damage and an increase in related cost savings are seen for all months, except March and April.

Statistical Change in Pavement Impacts from Baseline to Enforcement Year. To statistically confirm the occurrence of a decrease in pavement damage (measured in ESALs) from the baseline year to the enforcement year, a two-sample t-test with equal

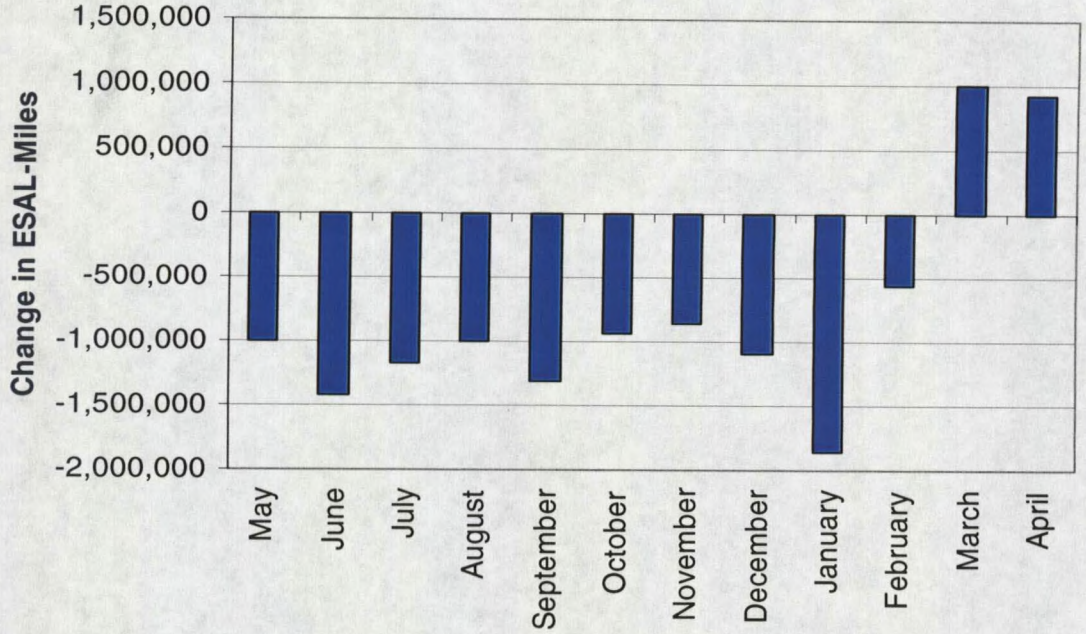


Figure 46. Statewide Change in Pavement Damage by Month, Baseline Year Compared to Enforcement Year.

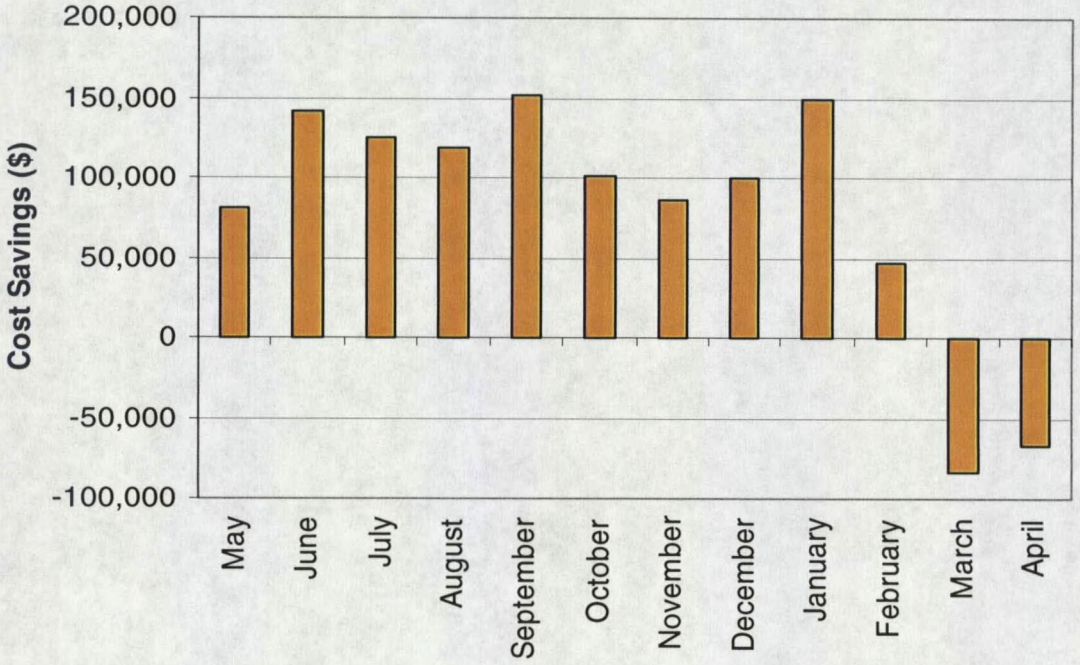


Figure 47. Statewide Cost Savings by Month, Baseline Year Compared to Enforcement Year.

variance was conducted. Using a 95 percent confidence level, the hypothesis that the mean pavement damage in ESALs during baseline and enforcement years are equal could not be rejected; the pavement damage is not significantly different between baseline and enforcement years (see Tables 6 and 7).

Table 6. F-test Results to Confirm Equal Sample Variances During Baseline and Enforcement Years.

	Baseline Year	Enforcement Year
Mean (ESALs/Site)	142,000	133,657
Variance	4.13×10^{10}	3.68×10^{10}
Observations	15	15
Degrees of Freedom	14	14
Calculated F-statistic	1.12	
Critical F-statistic	2.48	
P(F<=f) one-tail	0.42	

Table 7. Two-sample t-test Results to Confirm Equal Pavement Damage During Baseline and Enforcement Years.

	Baseline Year	Enforcement Year
Mean (ESALs/Site)	142,000	133,657
Variance	4.13×10^{10}	3.68×10^{10}
Observations	15	15
Degrees of Freedom	28	
Calculated t-statistic	0.12	
Critical t-statistic (two-tail)	2.05	
P(T ≤ t, two-tail)	0.91	

Because the enforcement year data includes both months of focused enforcement and months without focused enforcement, it is likely that an analysis such as this one is diluted. To account for this shortcoming, the total change in pavement damage and related costs (described below) specifically compared months of STARS enforcement to months without STARS enforcement rather than comparing the baseline year to the enforcement year

Total Change in Pavement Damage and Related Cost Attributable to STARS. As reported in Figure 48, ESAL-miles decreased between the baseline and enforcement years, with the majority of this change attributable to STARS enforced sites. Correspondingly, the cost savings associated with this change in pavement damage is again primarily attributable to the STARS enforced sites. The reduction in pavement damage statewide in 2001-2002 was on the order of magnitude of 10 million ESAL-miles of travel. The cost associated with this change in pavement damage was approximately $1 million. During non-enforcement months, a slight increase in total pavement damage (approximately 750,000 ESAL-miles) and a decrease in related cost savings (approximately $55,000) occurred during the evaluation period.

Citation Issuance Activity

Statewide citation issuance activity before and following STARS implementation was considered as a secondary investigation. A noted reduction in citation issuance activity occurred following STARS implementation, suggesting a change in commercial vehicle loading behavior (see Figure 49). A confounding factor that offers an alternate explanation for this phenomenon is a change in enforcement policy implemented during

the program that increased the allowable tolerance for a citable offense from seven to ten percent. Also, the shift in enforcement officer performance expectations from focusing on citation issuance to the reduction in pavement damage associated with their presence may further explain this reduction.

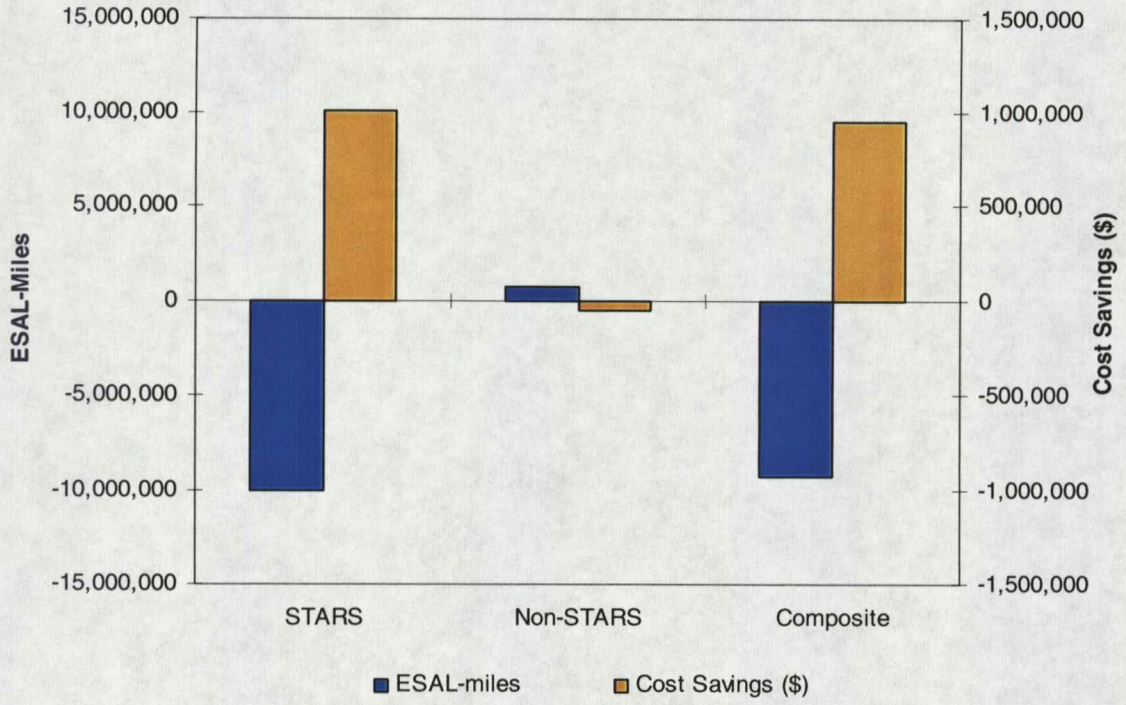


Figure 48. Change in Pavement Damage and Related Cost Savings Statewide, Baseline Year Compared to Enforcement Year.

To statistically confirm the decrease in citations issued from the baseline year to the enforcement year, a two-sample t-test with unequal variance was again conducted. Using a 95 percent confidence level, the hypothesis that the mean number of citations issued

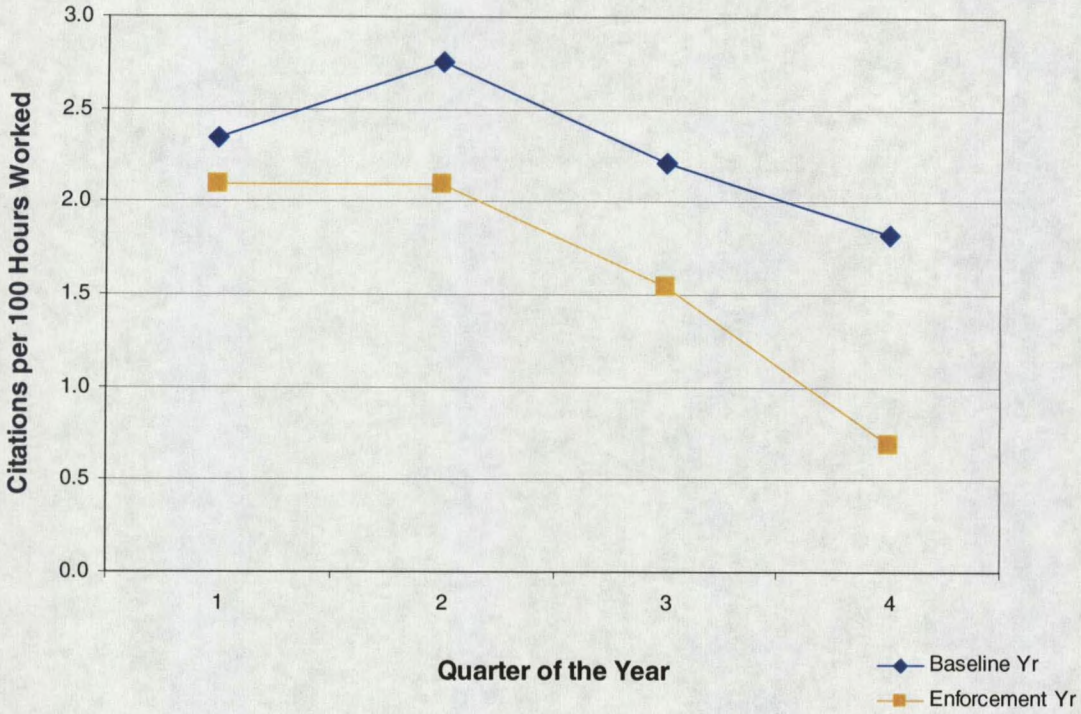


Figure 49. Overweight Citation Issuance

during baseline and enforcement years are equal could not be rejected (see Tables 8 and 9). Hence, although it is an important factor to consider, the difference in the number of citations issued between baseline and enforcement years did not result in a statistically significant reduction.

Table 8. F-test Results to Confirm Unequal Sample Variances During Baseline and Enforcement Years.

	Baseline Year	Enforcement Year
Mean (Citations/100 hrs.)	2.27	1.44
Variance	0.22	0.50
Observations	3	3
Degrees of Freedom	2	2
Calculated F-statistic	0.44	
Critical F-statistic	0.05	
P(F<=f) one-tail	0.31	

Table 9. Two-sample t-test Results to Confirm Equal Citation Issuance During Baseline and Enforcement Years.

	Baseline Year	Enforcement Year
Mean (Citations/100 hrs.)	2.27	1.44
Variance	0.22	0.50
Observations	3	3
Degrees of Freedom	3	
Calculated t-statistic	1.68	
Critical t-statistic (two-tail)	3.18	
P(T ≤ t, two-tail)	0.19	

Engineering and Planning Effects

Engineering and planning effects were detailed using a survey questionnaire distributed to various sections or divisions within MDT. Specifically, information related to the extent of benefits that may result from expanded and improved truck-related data was sought. Representative responses were obtained from the areas of:

- Planning
- Engineering
- Motor Carrier Services
- Pavements and Materials
- Geometric Design
- Safety and
- Bridges.

The survey questionnaire solicited information related to data use, data elements, data sources, data quality, data improvements and the overall benefit of an increase in the quantity and quality of truck-related data. As can be expected, the responses varied greatly from one area to the next. The Bridge Bureau did not respond to many of the questions contained in this survey.

Data Use

Survey respondents were asked to describe how they currently use truck-related data in their day-to-day activities. The Planning Division provides truck-related data to other divisions within MDT including Commercial Average Daily Traffic (CADT),

Commercial Vehicle Miles Traveled (CVMT), Equivalent Single Axle Loads (ESALs), Percent Large Trucks of AADT, Percent Commercial Trucks of AADT and Traffic Stream Distribution. The Materials Bureau uses ESAL data from the Planning Division to generate pavement surfacing designs and as part of their pavement management system.

The Engineering Division relies on truck-related data for site-specific design applications. The Geometric Design Section uses truck dimensional data for turning radii or lane widths and truck volumes and route data for locating climbing lanes. In addition, they use truck-related data in determining truck climbing lane warrants and in some cases the maximum grades for a facility. The data is also useful in developing justification for passing lanes on two-lane/two-way facilities. They also use truck crash data to locate and address site-specific problems. The Safety Management Section, within the Engineering Division, primarily uses truck crash information for safety reviews, for crash cluster analyses and to review locations with a high number of truck crashes.

Naturally, the Motor Carrier Services (MCS) Division uses truck-related data for a number of different purposes. MCS is responsible for Montana's oversize/overweight permitting program; all interstate and "fleet" commercial vehicle licensing and registration done in Montana; enforcement of Montana's diesel fuel tax laws; enforcement of state and federal commercial vehicle safety laws and regulations; annual certification of Montana's size and weight enforcement program to the FHWA (PLAN/CERT); annual certification to the FHWA of Montana's compliance with the Heavy Vehicle Use Tax (HVUT) requirements; administration of the International

Registration Plan (IRP) for Montana; administration of the federal Single State Registration System (SSRS) for Montana and development and implementation of the federally mandated Commercial Vehicle Information System Network (CVISN) program in Montana. All of these activities and responsibilities are dependent on various types of truck-related data.

Data Elements

Survey respondents were asked to list the types of data that they currently collect or access to support their day-to-day activities and what types of data they would like to see collected. The Planning Division currently collects data such as volume, length, speed, classification and weight and they are interested in having access to commodity information.

The Materials Bureau currently uses 20-year ESAL information provided by the Planning Division for their surfacing designs. The ESALs for the Pavement Management System are estimated based on a formula using AADT and percent commercial vehicles. The Materials Bureau is interested in having actual ESALs for their Pavement Management System.

The Engineering Division currently uses percent trucks, ESALs and truck crash data and they stated that, "seasonal fluctuations in truck volumes and origin/destination information may be useful for route segment planning." The Geometric Design Section currently uses the percent volume of trucks in the traffic stream, ESALs, and truck dimensions in plans development phase of a project. They did not request any additional data. The Safety Management Section currently uses Accident Investigator's Reports and

commercial truck volumes and is interested in vehicle miles traveled by truck class and by various roadway classifications. They would also like to see truck class volumes by route and by season and truck speed data by time of day and roadway classification. The Bridge Bureau deals with very heavy overweight vehicles, which require not only permits, but also route analysis. They use the full configuration, meaning distance between axles, front to back, and axle group weights.

MCS currently uses truck-related data for permitting, licensing, registration, financial, fuel, truck and driver safety, size and weight, enforcement activity and overweight incident data and did not request any further data.

Data Sources

Survey respondents were asked to identify their current sources for truck-related data. The Planning Division collects all of their data from the field by means of manual counts, automatic-sensing devices (such as WIM) and static scale sites.

The Materials Bureau responded by stating that design ESALs are provided to them in hard copy via memos and the Pavement Management System ESALs are calculated "on the fly" using data from the Planning Division's ORACLE tables.

The Engineering Division and the Geometric Design Section both receive all of their truck-related information from other units within MDT, most commonly from the Planning Division. The Safety Management Section of MDT gets the majority of their data from the Montana Highway Patrol database, the Transportation Information System (TIS) Road Log, TRADAS (traffic volumes), and/or manual traffic counts.

The Motor Carrier Services Division gets all of its truck-related data from various software programs and databases, as well as from the Planning Division.

The Bridge Bureau responded to this question by saying that they get all of their weight data, such as Gross Vehicle Weights (GVWs), from the Motor Carrier Services Division and that they get axle and wheel configurations from the truck companies themselves.

Figure 50 represents the flow of truck-related data through MDT. It can be seen in this figure that the Planning Division generally provides data to all sections. Due to different data needs, the Safety Management Section usually collects additional truck-related data. Also listed in Figure 50 are the types of truck-related data that are typically used by each area of MDT.

Data Quality

Participants were asked to list any shortcomings that they have experienced with the data that they currently access or collect and utilize. The most direct complaint about truck-related data was voiced by the Planning Division: "We spend all year collecting data and at the year's end, we need more data." This is significant because the Planning Division provides several other divisions with the truck-related data they need for their day-to-day activities.

The Engineering Division and the Bridge Bureau each said that there aren't any shortcomings with the data they receive. The data is essential to their function and the information really can't get any more detailed. However, the Geometric Design Section requested more detailed vehicle descriptions (i.e., sizes, number of axles). They also note

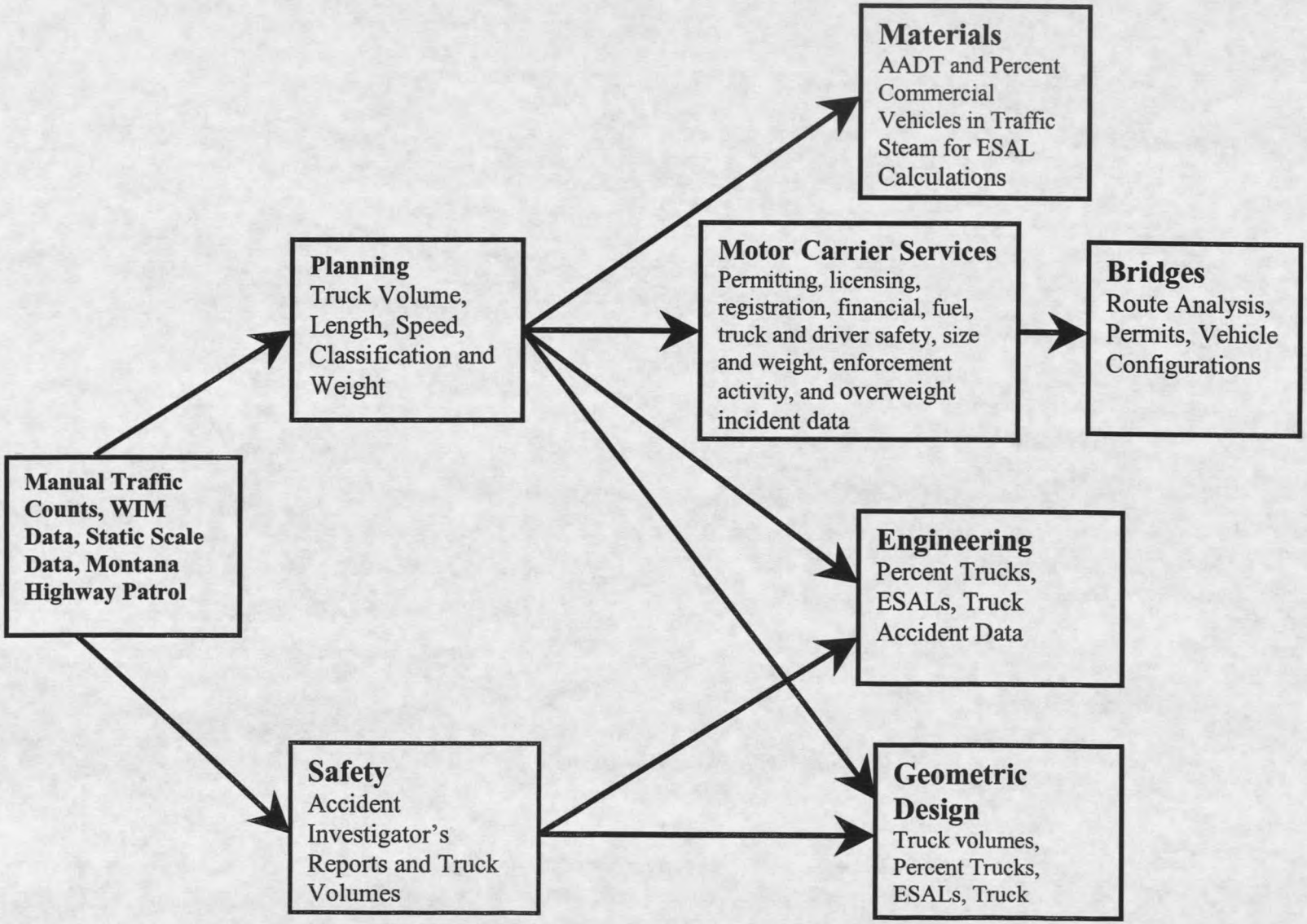


Figure 50. Departmental Flow of Truck-related Data

that unreported (after hours) truck volumes and overweight vehicles are not accurately shown.

The only complaint from the Motor Carrier Services Division is that some of the data is not easily accessible and requires the assistance of a technician.

Data Improvements

When asked how improvements in truck-related data available from the STARS program would affect their day-to-day activities, responses again varied. The Planning Division favors using WIM equipment because of its accuracy in weight and classification capture.

The Materials Bureau noted that this improvement in truck-related data would help with their need for axle load spectra data for the 2002 Design Procedure.

The Engineering Division doesn't anticipate that this improvement in truck data will have much of an effect on their jobs, but that easier access to data is always helpful. The Geometric Design Section is pleased that the data improvements will include truck size and number of axles. They would also like to see previously unreported truck volumes and overweight vehicles that should be included in their ESAL and volume data to accurately portray real-life conditions.

According to the Motor Carrier Services Division, "STARS provides MCS Managers with the ability to focus enforcement resources on a section of highway and at a time of day when overweight vehicles are known to have been in operation." They go on to say that, "Prior to STARS, this was a guessing game at best."

Benefits

Lastly, the survey questionnaire asked participants to rank the benefit that STARS will have on their day-to-day activities by selecting "Substantially Benefit," "Benefit," "Not Affect," and "Detrimentally Affect".

The Engineering Division and the Material Bureau thought that the improvement in data would "Benefit" what they do. Neither the Geometric Design Section nor the Safety Management Section provided an answer to this question. The Planning Division and the Motor Carrier Services Division both thought that the improvement in data from STARS would "Substantially Benefit" their day-to-day activities. The Bridge Bureau was the only area that didn't think the improvement in truck-related data would benefit what they do.

CONCLUSIONS AND RECOMMENDATIONS

The findings of this investigation suggest that MDT has succeeded in developing a program to effectively and efficiently utilize weigh-in-motion (WIM) data to improve overall commercial vehicle enforcement activity and achieve long-term infrastructure preservation. This report details the benefits of a pilot program related to truck weight enforcement, pavement performance effects, and expanded and improved truck weight and classification data for use in pavement design, engineering and planning efforts.

Generally, a reduction in the proportion of overweight vehicles during months of STARS focused enforcement was observed, but it was difficult to find consistency within these trends over time. This aspect of the evaluation would be greatly enhanced with multiple years of historical WIM data.

Comparisons before and after implementation of the STARS enforcement effort indicated that pavement damage was effectively reduced when this method for scheduling enforcement activities was used. There was an obvious decrease in pavement damage (ESALs) at those sites with more than six months of targeted enforcement. The effects became more difficult to see as the number of months of focused enforcement decreased.

In support of this finding, an obvious decrease in pavement damage (ESAL-miles) and an increase in related cost savings for the three vehicles configurations most often selected for focused enforcement (Class 9, 10 and 13) was also observed. The reduction

in pavement damage and increase in related cost savings attributable to these three vehicle classes accounted for over 96 percent of the total reduction and savings.

The overall reduction in pavement damage attributable to the STARS program statewide in 2001-2002 was on the order of magnitude of 10 million ESAL-miles of travel. The cost savings associated with this change in pavement damage was approximately $1 million.

Citation issuance was also considered as a secondary metric for STARS program performance. A decrease in the number of citations issued between baseline and enforcement years was observed, although the difference was not statistically significant. The moderate reduction is ideally due to a shift in commercial vehicle loading behavior, but may also be explained by an MDT policy change in the allowable tolerance for a citable offense from seven to ten percent.

With respect to engineering and planning benefits attributable to STARS, the degree to which benefits can be realized varies from one area within MDT to another. Motor Carrier Services and Planning Divisions perceive the greatest resulting benefit, while the Engineering Division anticipates a lesser degree of benefits.

The STARS program would possibly provide greater and more continued benefits if an increased number of years of historical data were available on which to base the determination of sites, months and configurations for the focus of enforcement. With this additional historical data, the targeting of enforcement would become more reliable and the exploration of abnormal increases in commercial vehicle operations would also be

simplified. Had more historical data been available prior to this investigation, questionable data could have been further scrutinized for appropriate inclusion.

Another issue to consider at the close of this investigation is whether or not the same techniques used in this pilot project to select enforcement sites can be used in the future. The observed effects of this pilot STARS program may in fact decrease future effectiveness as the motor carrier industry adjusts their vehicle loading behavior. With this in mind, the MCS Division of MDT is committed to continuing to investigate techniques to improve their effectiveness and strongly believe that WIM will continue to have a role in their future enforcement activities.

The approach of using STARS to guide and evaluate the state's weight enforcement program is being put forth as a possible performance-based alternative to the system currently used by the FHWA (Federal Highway Administration). By shifting the existing performance metric from overweight vehicle capture and citations issued to the reduction in pavement damage, a more direct, effective, objective and nationally comparable state enforcement program would result. Further, STARS complements the ITS/CVO Commercial Vehicle Information Systems and Networks (CVISN) initiative and significantly contributes to the successful achievement of the national Long Term Pavement Performance (LTPP) program objectives.

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