EVALUATION OF VIOLATION AND CAPTURE OF OVERWEIGHT TRUCKS: A CASE STUDY

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16. ABSTRACT

This report concludes the four phase evaluation of Washington's fee and fine system. The primary focus of this report is the occurrence and capture of overweight vehicles at three selected evaluation sites in Eastern Washington: Pasco, Chattaroy, and Cashmere. Weigh-in-motion data was utilized to determine any changes which occur in truck traffic when weight stations are open and closed. Violation rates are estimated between 20% and 22% with capture rates between 20% and 27%, depending on the site. Violation and capture rates, in addition to truck volume and axle weights, are further calculated for different truck types during all hours of the day. The analysis also includes seasonal variations in all variables.

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EVALUATION OF VIOLATION AND CAPTURE OF OVERWEIGHT TRUCKS: A CASE STUDY

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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SUMMARY

Washington's transportation system provides a critical service to the region's producers, consumers and manufacturers through the use of an intermodal transportation network that allows the movement of people and products in a safe, timely and efficient manner. This transportation network consists of modal choices for freight movement including truck, rail, barge and air transport. One important component of this intermodal network is the state's road and highway system which has experienced accelerated deterioration in recent years from numerous trucks, some of which are loaded heavier than legal limits. Any deterioration of the state's road and highway system due to overloaded trucks has economic implications for area businesses in addition to creating a competitive disadvantage to truckers who abide by truck weight limits.

The state's fee and fine system has been legislated to control, through deterrence or financial recovery, the impact of overweight vehicles on roads and highways. The system is designed to either eliminate the economic incentive to overload or recover the road damage attributed to the extra weight through an appropriate fee and fine schedule.

Once an effective fee and fine system is designed, it is then implemented in a two step process consisting of enforcement efforts and the judicial process. Enforcement officers administer the weight restrictions and regulations to sufficiently encourage truckers to purchase overload permits when overloaded and provide the disincentive to overload via fines. The court/legal system completes the process by facilitating an effective adjudication process which allows recovery of financial damage attributed to overweight violations.

This report is the final phase in a series of four reports investigating the effectiveness and appropriateness of Washington State's fee and fine system through evaluation of the complete fee

and fine process mentioned above. Each report (available from the Washington State Department of Transportation) examines, in greater detail, the success of each process in achieving a fee and fine system which maximizes the benefits from the existing highway system. The effectiveness of the "total system of weight enforcement" relies on each subsystem operating efficiently and equitably. Information generated in the overall research project can guide implementation of that subsystem.

Report Summaries

Phase I, titled *"A Case Study of Motor Vehicles Violating Special Weight Permits in the State of Washington"*, evaluated the degree and frequency in which overweight permits are violated and developed a truck profile of those who violate truck weight permits in Washington. All citations issued between November 1, 1991 and October 31, 1992 for permit violations in the state were utilized to develop information about motor carriers who had obtained an extra tonnage permit, but then violated it. The information included on the citation, such as the date and location the violation occurred, arresting officer, permittee name and address, permit type, commodity hauled, origin/destination, and overload magnitude, helped identify the type of trucks which are violating overweight permits and develop a truck profile.

The results from this report indicated that the majority of citations from overweight permit violations occurred at permanent scale houses (81%), compared to portable scales used at random locations. Of the citations issued, 74% were issued on the west side of the state with only 26% issued in Eastern Washington. Seasonal analysis revealed that an average of 60 permit violations per month occurred during the study period, with a larger proportion of citations issued during

the winter months (67 per month for November through February) than the summer season (53 per month for May through August). The commodity category with the largest number of permit violations was Machinery, Except Electrical with 93 citations, followed by Lumber or Wood Products with 57 citations. This information, in addition to more detailed analysis in the actual report, contributes to the identification and nature of overweight permit violations.

The second report, titled "*A Case Study of the Effectiveness of Washington's Fine System for Overweight Violations*", examines the effectiveness of the state's fine system in recapturing the physical and resultant financial damage to pavements caused by overloaded vehicles, through the court and legal process. This is accomplished through interviews with weight enforcement officials and court personnel in addition to a detailed examination of over 8,000 citations from nine counties between September, 1991 and August, 1992.

The majority of citations issued during this time period were paid (63%) without contesting the citation. Another 32.6 percent paid the fine after attending court, demonstrating that over 95 percent of overweight citations issued during this time period were paid. Evaluation of the defendants' addresses revealed that Canadian and out of state residents paid an average of over 90 percent of the original fine on all cases while Washington residents paid an average of 83.2 percent of the original fine. Hence, defendants who live in Canada and out of state tend to pay their fines rather than returning to contest their case in court. However, of those cases which are contested in court, only 63 percent of the original fine is paid, indicating that 37 percent of potential revenue is being "lost" in the court system. Judges frequently assigned penalties between 61 and 70 percent of the original fine whenever citations were contested.

The third report, titled *"An Evaluation of County and City Road Weight Enforcement*

Efforts in the State of Washington", investigated the degree and methods of participation in road weight enforcement programs for cities and counties in the state. A survey of cities and counties throughout the state revealed that larger cities and more urban counties have greater involvement in weight enforcement programs, whereas smaller cities and more rural counties have less involvement. Only six cities in the state were directly involved in weight control enforcement programs with Seattle and Tacoma having the most active programs. Eleven of the 39 counties in the state were identified as having full weight enforcement programs and 5 counties had only partial weight enforcement programs. These results could indicate a probable need for heightened weight enforcement programs in smaller cities and rural areas where transport of heavy agricultural and wood products is known to generate substantial truck traffic.

This final report, titled *"An Evaluation of Violation and Capture of Overweight Trucks in Eastern Washington"* investigates the occurrence and capture of overweight vehicles at three selected evaluation sites in Eastern Washington: Pasco, Cashmere and Chattaroy. The analysis utilizes weigh-in-motion devices, situated within close proximity of weigh stations, to determine any changes which occur in the truck traffic when the scale is open and when it is closed. Vehicle observations for the year 1994 allowed investigation of seasonal variations in the violation and capture rate in addition to differences due to truck type.

Capture rates ranged anywhere from 0% to 62% with an estimated total capture rate for the year of 20%, 27% and 21% at Pasco, Cashmere and Chattaroy, respectively. These rates are about double the overall 10% capture rate estimated in a previous study (Casavant, 1991). Hence, enforcement efforts, in terms of choosing the appropriate hours of weigh station operation, appear relatively effective, while still missing a significant number of overloaded trucks.

Pasco and Chattaroy had violation rates of 22% while Cashmere's violation rate was slightly lower at 20%. These estimates are at the higher end of the range quoted in previous studies and indicate a substantial amount of overloaded trucks on the highway. This study also classified trucks into three truck type categories including straight trucks, single-trailer trucks and double-trailer trucks. Double-trailer trucks experienced the largest violation rates, followed by single-trailer and straight trucks, respectively. Avoidance activity was not found to be a substantial problem at weigh stations in Pasco and Cashmere. However, some evidence of avoidance was evident at the Chattaroy site. The summer season generally had the largest truck volume at each site reflecting the increase in business activities associated with this time period. Seasonal variations in the violation and capture rate were also noticed, but varied by location with no consistent pattern for all sites.

Conclusions

Each report has targeted an important aspect of Washington's fee and fine system in an attempt to determine how effective the total system currently is, and identify areas which could improve the systems effectiveness in controlling and capturing the financial damage from overweight vehicles. Several meaningful observations have surfaced which could, if appropriately applied, significantly improve the current system.

The occurrence of overweight vehicles on Washington's roads and highways is possibly more substantial than previously thought. An average of 60 overweight permit violations per month for the state indicates considerable overloading activity, especially considering this estimate only includes those vehicles which had originally purchased an overweight permit. A significant

number of overweight violations can certainly be expected from vehicles without permits. Estimated violation rates between 20% and 22%, which include any truck exceeding axle weight limits, also demonstrates the magnitude of overweight occurrences.

Fortunately, this analysis has generated some information about vehicles which overload and the areas where they most frequently occur. The commodity category with the largest number of overweight permit violations was Machinery, with Lumber or Wood Products having the second largest number of permit violations. Also, double-trailer and single-trailer trucks were found to have the highest violation rates, in addition to the heaviest axle weights. Enforcement officers can incorporate this information to target overloaded vehicles more efficiently at each site by evaluating the truck traffic flow characteristics at each site and designing an enforcement schedule accordingly.

The judicial process may also be thwarting the effectiveness of the fine system by frequently assigning penalties which are considerably less than the original fine amount. Of all cases contested in court, only 63 percent of the original fine is paid, resulting in a loss of 37 percent of potential revenue. Given the magnitude of overweight occurrence, this may have substantial impacts on the longevity of the road and highway system and preservation of its capacity to service shipper needs.

INTRODUCTION

The transportation system of Washington serves many useful functions which influence the social welfare of individuals within and outside the region's geographical boundaries. The movement of product and people in a safe, timely and cost efficient manner contributes to the economic growth and vitality of all agents in the economy and serves as the critical link between production and consumption activities. One crucial component of that transportation system is the highway and road system.

Over the past several years there has been heightened concern over the accelerated deterioration of the highway and road system, both within the state of Washington and nation wide. State and federal transportation planners continually monitor highway and road conditions and forecast future needs by modeling these traffic flow characteristics for each highway and road segment and allocate available funds accordingly. Traffic flow characteristics such as vehicle counts and classification are typically easily determined for given highway segments. However, one component of traffic flow characteristics which has been difficult to estimate historically, and one that weighs heavily in the highway and road life expectancy equation, is the occurrence of overweight trucks (above the legal weight limit) on highways and roads.

The economic impacts from overweight trucks are considerable. Pavement damage increases exponentially as vehicle axle weight increases. Overloaded trucks, therefore, create increasingly more highway and road damage, resulting in shorter pavement life-expectancy and sooner highway rehabilitation and reconstruction needs. The financial impact on state highway funds and government expenditures can be severe considering the 79, 432 total statewide miles of streets, roads and highways in the state of Washington (WSDOT, 1995).

The proportion of overloaded trucks to total truck traffic, known as the ***violation rate,*** has been preliminarily estimated in various reports to range anywhere from 5 to 28 percent (Casavant). Most quantitative estimates are derived from weigh stations where trucks are weighed and cited for any overweight offense. The difficulty in obtaining an accurate total population estimate, relying on such a methodology, is that most weigh stations don't operate continuously, many trucks are known to avoid weigh stations when stations are in operation, and some trucks (local, assembly, etc.) simply do not use roads where weigh stations occur. Hence, the estimated violation rate doesn't account for the entire truck traffic population at a particular site and could be considerably lower than the violation rate which actually exists. While few scientific studies have successfully investigated the overweight truck violation rate, a recent WSDOT study reported that 18% of containers loaded onto trucks at Washington ports were overweight (Tolliver et al.)

Similar difficulties are associated with determining the proportion of overweight trucks which are actually captured, known as the ***capture rate***. Avoidance activity around weigh stations varies, depending on the site and the ease and accessability of by-pass routes. The capture rate for overweight trucks going through static weigh stations when open is reasonably close to 100 percent. Unfortunately, due to limited spatial coverage in a state, non-continuous operating weigh stations, and avoidance activity around weigh stations, all overweight trucks aren't captured on a given segment of highway or in the total region. Previous estimates of the capture rate range anywhere from 5 to 15 percent. Casavant and Lenzi tentatively estimated the statewide capture rate to be approximately 10 percent in the state of Washington.

Washington's fee and fine system is designed to both deter the economic incentive to

overload and, when the economic incentive to overload is greater than damage caused, recapture the resultant financial damage incurred from overloaded trucks. Underlying that designed fee and fine structure is the extent of overweight vehicle occurrences on the state's roads and highways and the level of successful enforcement of weight regulations.

OBJECTIVES

The overall purpose of this study was to empirically estimate the violation and capture rate of overweight vehicles in Eastern Washington. Specific objectives were to use selected case studies to:

1) Determine any significant difference between the number of trucks, the weight (both gross and axle) of trucks and the number of overweight trucks when the weigh station is open and when it is closed.

2) Investigate the relationship between traffic characteristics (commodity, length of haul, hour of movement, etc.) and weight.

3) Depict the relationship between both truck and axle weight and the 24 hour time span in a day, thus illustrating the dynamic changes which occur during the hours the weigh station is open and closed.

4) Determine the violation and capture rate of overweight trucks for all hours in a day.

CONCEPTUAL FRAMEWORK

The incentive for truck overloading is often an economic one as truckers and shippers strive to maximize profits and/or survive in a competitive market. Lower per unit transportation costs from overloading can encourage companies and truckers to assume the risk of being captured and fined. The economic incentive or the willingness to overload can be conceived as a function of six influences or variables. This relationship can be symbolically written as follows.

$$D_o = f(H(F, C, V, J), P)$$

where:

D_o = the demand for overloading
H = the net fine observed by truckers
F = the initial fine for overloading
C = the enforcement level or capture rate
V = the violation rate
J = the judicial process
P = the net value of the tariff paid or cost savings realized

The net fine observed by truckers (H) is influenced by the legislative, executive and judicial branches of government as reflected by the initial fee and fine system, the enforcement level or capture rate and the final judgement rendered through the judicial process. Together, these forces determine the implicit price, or economic cost of overloading. An increase in the initial fine system and enforcement levels has the effect of increasing the net fine observed by truckers. The benefit from overloading is determined by (P) the per unit value of tariff or cost savings. An increase in the per unit rate results in an increase in the quantity demanded for overloading. Conversely, the relationship between "H" and the demand for overloading, the focus of this study, is negative since increases in the net fine observed by truck operators typically result in a decrease in the demand for overloading. These relationships can equivalently be expressed symbolically.

$$\frac{\partial D_o}{\partial P} > 0 \qquad \text{and} \qquad \frac{\partial D_o}{\partial H} < 0$$

Several different types of pavement damage functions have been used to estimate pavement deterioration. The initial pavement damage function designed by the American

Association of State Highway Officials (AASHO) follows the general relationship expressed below (Tolliver).

$$d = \left(\frac{N}{\tau}\right)^{\beta}$$

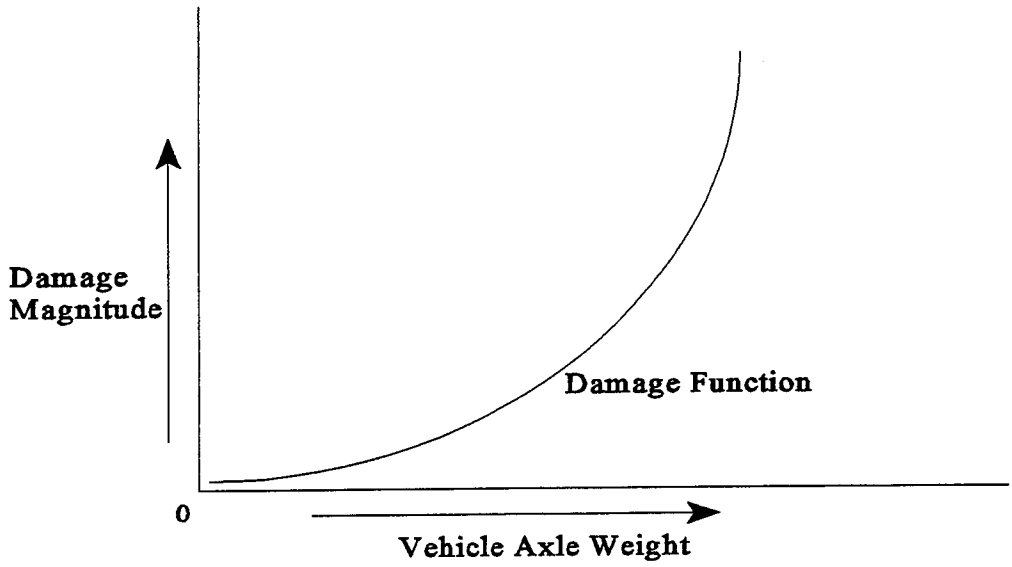
where:

d =	the measure of pavement damage
N =	the number of passes of an axle group of specified weight configuration
τ =	the number of axle passes required to completely consume the road segment
β =	rate of deterioration

Slight modifications to this initial functional form and changes in the specification of estimating the two unknown parameters τ and β have led to alternative pavement damage models such as the one employed by the Highway Performance Monitoring System (HPMS) and the one developed by Rauhut et al., and used by the Federal Highway Administration (FHWA). While there are many factors which influence the level and rate of pavement deterioration (such as pavement type, soil type, subgrade strength, climatic changes, tire pressure, etc.) the relationship between truck axle weight and pavement damage, emphasized for the purpose of this study, follows the general pattern illustrated in Figure 1. As vehicle axle weight increases, the damage to pavement increases at an increasing rate.

Washington's fee and fine system is designed to control the occurrence of overweight vehicles on the states highway and road system by setting fees and fines commensurate with either recapturing resultant road damage or deterring the economic incentive to overload. The goal is not to minimize the number of overloads, but to maintain a fee and fine system that will capture

Figure 1. Relationship between pavement damage and vehicle axle weight



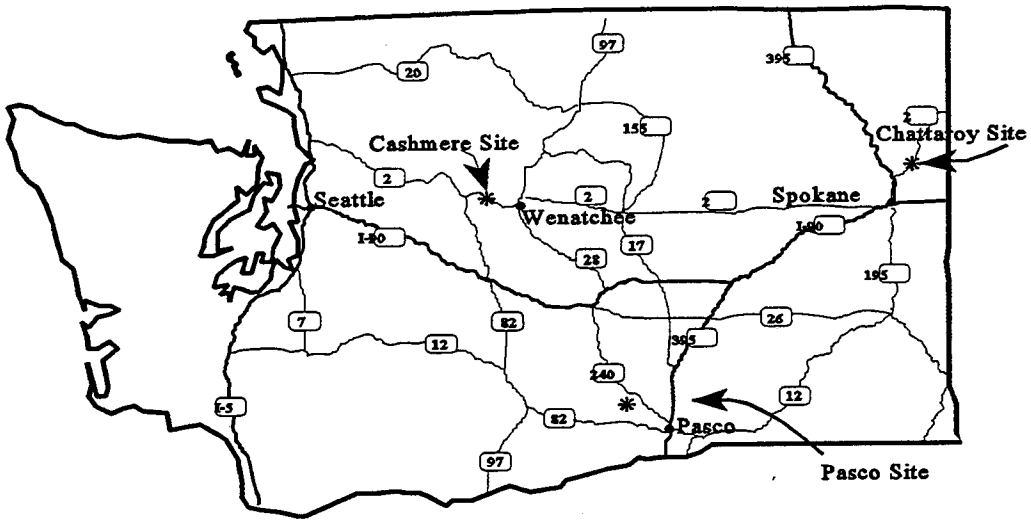
any highway damage attributable to overloaded trucks while allowing motor carriers the option of overloading if the cost savings exceeds the penalties of doing so. However, critical to the implementation of an appropriate fee and fine structure and truck weight limits is the level of successful enforcement (Fekpe). Basic to this is an estimation of the violation and capture rate of overweight vehicles, the focus of this study.

METHODOLOGY

The general approach of this study was to compare the differences in truck traffic flows and characteristics concerning truck and axle weights when the weigh station is open and closed. This allowed investigation of the extent and nature of avoidance activity around weigh stations and aided an estimation of overweight truck violation and capture rate. Avoidance activity consists of any activity by truckers to avoid being weighed, such as by-passing the weigh station

during open hours or waiting at truck stops and rest areas until the weigh station is closed. Reasons for avoiding the scales may include being overweight, not having an accurate, updated log or fear of failing a safety inspection. In pursuit of these goals, three case study sites on state routes in Eastern Washington which had both 1) a non-continuous operating weigh station and 2) a Weigh-in-Motion (WIM) site within close proximity of the weigh station (see Figure 2) were selected. These three sites were chosen because very few sites in the state possess both of these characteristics.

Figure 2. Site Locations in Eastern Washington



Site Descriptions

Chattaroy Site

The Chattaroy site is located in northeastern Washington on SR2, approximately 10 miles north of Spokane. The weigh station is located in the south bound lane at approximately mile-post 302, with the weigh-in-motion device only a few hundred feet south of the station.

Several by-pass opportunities for traffic wishing to avoid the scales exist: use of a

secondary state road which parallels the south bound lane and can be easily accessed north and south of the weigh station; and use of nearby SR395.

This region is quite rural with forestry and agricultural comprising the predominate activities. A recent report by Gillis and Casavant highlighted the profile of trucks passing through this region as part of a state wide origin and destination study. Nearly two-thirds of all southbound traffic were found to be empty trucks returning to Spokane after making local area deliveries. Also, two-thirds of all loaded trucks were carrying wood products with the remaining shipments being agricultural commodities, machinery, sand, solid waste and general freight. Thus, there is a large proportion of short distance local trucks traveling this highway segment. It can be reasonably expected these trucks move more typically during business work-day hours.

Cashmere Site

Cashmere is a small community west of Wenatchee, Washington located in the central part of the state. The WIM site is located at mile-post 113 on SR2, only a few miles west of Wenatchee and eight miles east of the weigh station. This weighing facility is located on the westbound lane, thus weighing only westbound truck traffic. Ideally, the WIM location and the weigh station should be within close proximity to allow accurate comparisons between the two different data sources. However, the distance between the two sites shouldn't be a significant problem given that no major highway intersects between the two sites.

This area is very similar geographically to the Chattaroy site in the sense that it is a rural region with agricultural and forest products generating the large proportion of freight truck traffic. However, only one by-pass opportunity exists for trucks seeking to avoid this scale which

is a secondary road that turns off just east of the station and reenters SR2 a short distance past the station. The by-pass exit is visible from the weigh station and a sign at the exit warns trucks about truck avoidance enforcement. Hence, avoidance activity around this weigh station is probably not a significant problem.

Pasco Site

This site is located in southeastern Washington on SR395, approximately 10 miles north of Pasco. The weigh station is located on the southbound lane at about mile-post 32. The weigh-in-motion device is located at mile-post 27, only five miles south of the weigh station. There is considerably more traffic at this site compared to the Chattaroy site, which is reflected in the greater number of hours throughout the year this station is open. The larger traffic volume is reflective of the geographic location of this site with respect to its proximity to area business and commerce, in addition to being a major thoroughfare for interstate and intrastate north-south movements.

The by-pass opportunities are even more abundant for this site than at Chattaroy. A secondary state road west of SR395 offers a parallel alternative with at least two exit opportunities north of the weigh station and four re-entrance locations south of the station. Trucks interested in avoiding this station could easily do so with minimal hindrance or time delay.

This general area in Eastern Washington represents a major collection point for many of the agricultural commodities and natural resources produced and moved throughout Washington and surrounding states. Fresh fruits and vegetables are produced in significant volume in the Columbia River Basin and commonly move through the tri-city region (Pasco, Kennewick and

Richland, WA) for processing and export. Wheat and barley from the Palouse region in Eastern Washington is transported via truck to river ports in the tri-city area to capitalize on the inexpensive barge mode of transport. A significant amount of long distance truck movement exists along this route from trucks originating in Canada and the northern tier states destined to ports on the west coast or mid west markets (Casavant and Gillis).

Data

Two primary data sources were utilized in this study. Hours of operation for each weigh station were obtained from the Budget and Fiscal Services of the Washington State Patrol. Actual raw report files of truck information from the weigh-in-motion sensors at each site were provided by the Transportation Data Office within the Washington State Department of Transportation. All truck records from each site for the entire year of 1994 were utilized except for any short time periods at each site when sensor failure resulted in inaccurate readings.

Weigh-in-Motion Considerations

Questions about the accuracy of WIM data (Izadmehr, Cunagin) may cause concern for studies of this type where individual trucks are categorized as being either overweight or within weight limits. This concern arises from variations of factors such as speed, temperature, pavement condition and tire pressure which influence truck weight readings. While the weight estimates are not as accurate as static scale readings, they can be useful for analyses of this type if properly calibrated, seasonally adjusted and, above all, consistent over time.

WIM sites within the state of Washington are automatically calibrated weekly using front

axle weights (which are typically more accurate) and temperature adjustment factors to continually adjust the weight readings for any changing conditions. In addition to being continually monitored for any problems, WIM sites are frequently tested for accuracy with several passes of a truck with a known weight (McFayden, 1995). Also considering the large number of observations included in this analysis, and assuming an approximate normal distribution, the observed truck weight readings should reasonably converge to within a fairly narrow interval of the actual truck weights.

Statistical Procedures

After the individual sites were identified, the six variables listed below were utilized to conduct the analysis.

Variable Name	Description
1. NTRK	Total number of trucks (includes all truck classification types), per FHWA vehicle classification
2. OVRGW	Total number of trucks violating gross vehicle weight limits of Washington statute
3. OVRXL	Total number of trucks violating axle weight limits of Washington statute
4. OVBTH	Total number of trucks which are in violation of both axle and GVW limits
5. AGVW	The average gross vehicle weight
6. AXLW	The average axle weight

Any truck which exceeded the maximum permitted gross vehicle weight was identified as being overweight on GVW limits and accounted for under the OVRGW variable. Any truck which exceeded 20,000 lbs. on any single axle or 34,000 lbs. on any set of tandem axles was identified as violating axle weight limits and counted under the OVRXL variable. The variable OVBTH

identifies any truck which exceeded both axle and gross vehicle weight limits.

Each of the six variables were then independently regressed against an indicator variable identifying the hours when the scale was closed (0) and when it was open (1) to identify the effect of these two time periods and investigate the occurrence of avoidance activity. The relationship between the number of trucks and whether the scale is in operation generally has no a priori expectation except that enforcement officers are often expected to open the weigh station during heavier traffic movement. One would preliminarily expect a decline in the number of overloads, in addition to a decline in the average vehicle and axle weight, when the weigh station opens, and a corresponding increase in the same once the weigh station closes.

Violation and Capture Rate Calculations

The violation rate is calculated for the open and closed time periods for each hour. The estimated violation rate for when the weigh station is open (closed) is the number of overweight trucks for the hour divided by the total number of trucks in that period. The estimated violation rate for the year is determined by taking the rate from each hour and multiplying by the percentage of trucks occurring in each hour for the year and then summing across all 24 hours.

The capture rate is calculated in the following manner.

$$Capture\ Rate = \frac{A}{A+B}$$

where: A = the number of overweight trucks per hour open
B = the number of overweight trucks per hour closed

This calculation of the capture rate assumes that avoidance activity is not a substantial problem

since it implicitly assumes that the number of overweight trucks per hour open represent 100% of the overweight trucks which would be passing through this route regardless of whether the station is open or closed. If avoidance activity around the weigh station is substantial, then "A" in the above equation should be multiplied by the actual percentage of total trucks which are not avoiding the scale. For example, if the violation rate is 20% during closed hours and 10% during open hours, then "A" above should be multiplied by (1- .1) or 90% since ten percent (20%-10%) of the overweight trucks are avoiding the scale and only ninety percent are actually going through the scales. However, the following results of this preliminary study indicate that avoidance activity does not appear to be a significant problem.

RESULTS

The results of the statistical analysis are presented in Table 1 for each site.

Table 1. Statistical results from the Pasco, Cashmere and Chattaroy Site

		t-values		
	Variable	Pasco	Cashmere	Chattaroy
1.	NTRK	23.77	35.59	19.84
2.	OVRGW	10.68	21.58	13.83
3.	OVRXL	13.58	33.26	16.59
4.	OVBTH	8.00	18.50	10.44
5.	AGVW	-7.38	2.34	3.40
6.	AXLW	-5.41	9.24	10.16

All variables are significant at the 99 percent confidence level. The t-values which are positive, variables 1, 2,3 and 4, indicate a positive relationship between each variable and the opening of the weigh station since the indicator variable representing each weigh stations status is "0" for closed and "1" for open hours. Negative t-values indicate an inverse relationship.

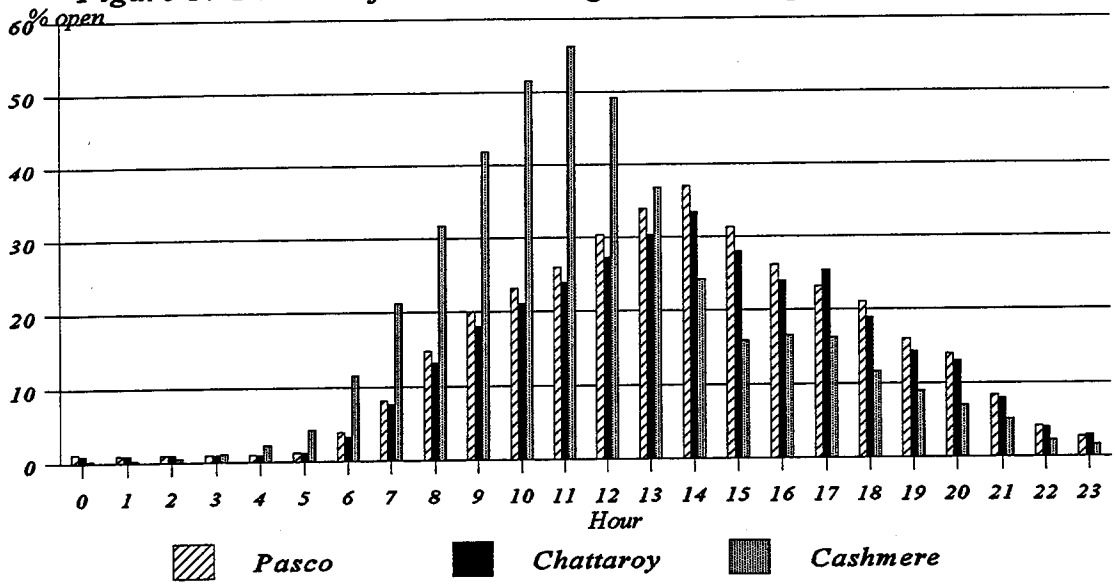
These results are interesting for two reasons. First, if avoidance activity is a substantial problem, as many CVEO's believe, then one would expect the opposite relationship for variables 2 through 4 at all sites. The opening of the weigh station should be related to a decrease in the number of overweights with the closing of the station rendering the opposite relation. And second, given the relationships established with variables 2 through 4, one might initially expect variables 5 and 6 from the Pasco site to exhibit positive relationships, as they do with the Cashmere and Chattaroy sites, since as the number of overweight trucks increase, one could expect the average gross vehicle and axle weight to increase also. However, the following broader examination of the three sites provides a plausible and realistic explanation for these seemingly unusual results.

Annual Analysis

Average Truck Volume

It is first useful to identify the hours throughout the day that each weigh station is actually open during the year (Figure 3). It is quickly obvious that these particular weigh stations are open predominately between the hours of 8:00 am and 5:00 pm and all are open 55% or less on the year. The increase in truck traffic follows the same general pattern as the weigh station hours of operation for each site (Figures 4, 5 and 6). The reason for this truck traffic pattern is not

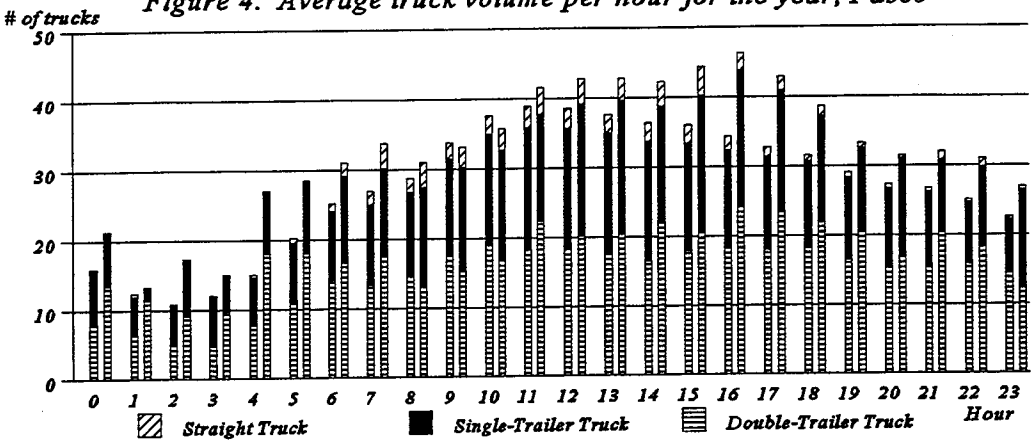
Figure 3. Percent of time each weigh station is open for each hour



because of the opening and closing of the weigh station but rather due to the normal transportation demand by business operating hours of construction companies, grain elevators, garbage businesses, rock quarries and other entities generating truck traffic. Hence, it comes as no surprise that there is a positive relationship between the number of trucks on the highway and the opening of the weigh station. In fact, if the opposite held, a reorganization of station open hours would be appropriate.

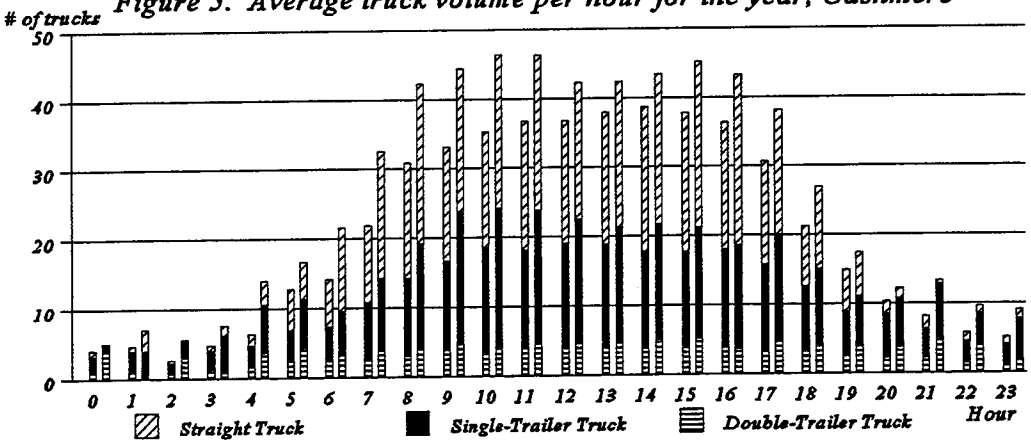
The average truck volume per hour at each site is further categorized into three general truck type configurations including straight trucks, single-trailer trucks and double-trailer trucks. There are several important observations from these three figures which should be noted. First, the truck volume is heavier at the Pasco site than at the other two

Figure 4. Average truck volume per hour for the year, Pasco



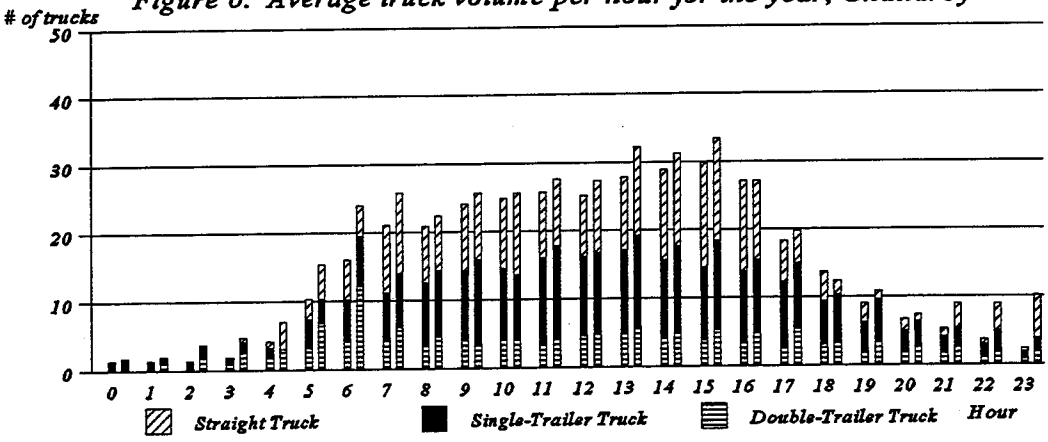
** The first and second column in each hour represents "closed" and "open" weigh station counts respectively.*

Figure 5. Average truck volume per hour for the year, Cashmere



** The first and second column in each hour represents "closed" and "open" weigh station counts respectively.*

Figure 6. Average truck volume per hour for the year, Chattaroy



** The first and second column in each hour represents "closed" and "open" weigh station counts respectively.*

sites with Chattaroy having the lowest truck volume. The type of trucks at each site differs significantly also with Pasco truck traffic being largely single-trailer and double-trailer trucks whereas Cashmere and Chattaroy traffic is mostly straight trucks and single-trailer trucks. Truck traffic of all types decreases dramatically during non-business hours at the Cashmere and Chattaroy site but is less pronounced at the Pasco site. This reenforces the belief that long distance trucks are more prevalent at the Pasco site with Cashmere and Chattaroy having mostly short distance truck traffic.

Average Overweight Truck Volume

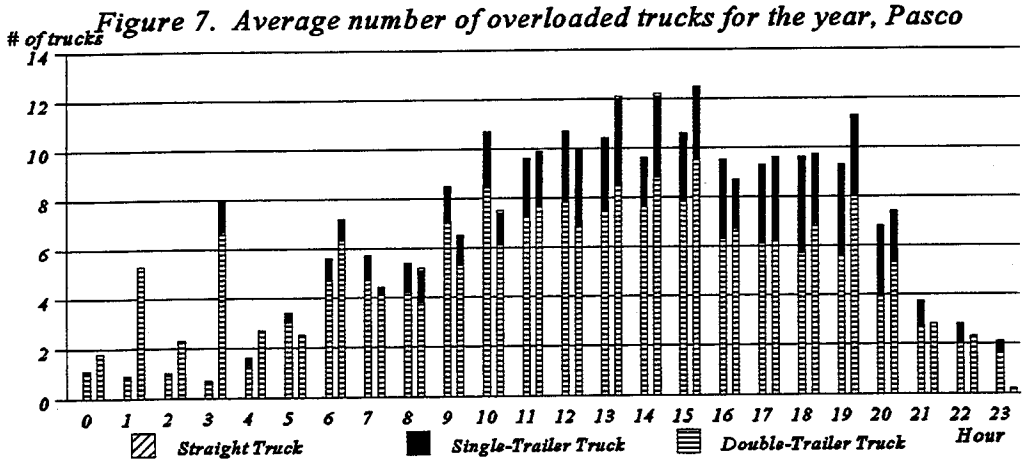
The increase in the number of overweight trucks (both from gross vehicle and axle weight limits) related to the opening of both weigh stations is also partly due to this truck traffic increase during the regular working hours of 8:00 am to 5:00 pm. Generally, the large majority of truck traffic increase during these hours are "short distance" trucks as indicated by the review of truck traffic type at each site earlier and from the increase in the number of overweight straight and single-trailer trucks at each site in Figures 7, 8 and 9. There will also be an increase in the number of "long distance" trucks during this time period, but proportionately smaller than the increase in short distance trucks. This is significant because the different operating characteristics of each truck type partially explains the relationships with variables 2 through 6 at each site. Short distance trucks are frequently making several trips within the general geographical vicinity of the business activities they are involved in, often making their return trips empty. When loaded, short distance trucks may tend to exceed weight limits due to 1) truckers who are paid by the ton hauled as is the case for some timber and farm products, and 2) the difficulty of knowing the exact

weight of certain trucks when they are loaded, such as those which haul dirt, rock, garbage and farm produce. The combination of an increase in truck traffic from trucks which are frequently loaded heavy when loaded, and often make return trips empty, results in a corresponding increase in the number of overloaded trucks during the hours of 8:00 am to 5:00 pm while the average gross vehicle and axle weight declines at the Pasco site. Then once the weigh station closes and the proportion of long distance trucks on the highway is greater than the number of short distance trucks, the reverse is seen.

The Cashmere and Chattaroy sites experience a different situation as a result of fewer long distance trucks utilizing these segments of SR2. Whenever truck traffic increases during regular working hours there is a related increase in the number of overweight trucks, and the average gross vehicle weight and the average axle weight increase since the influence of long distance truck characteristics does not exist.

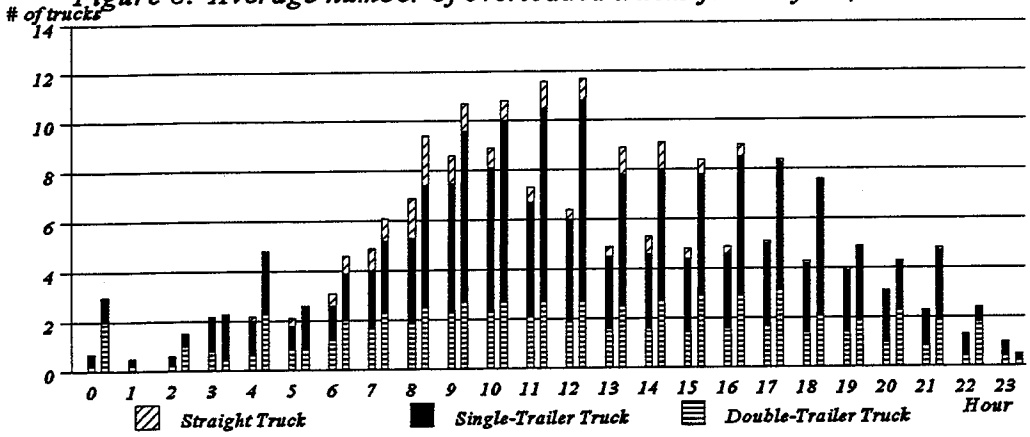
These two relationships are visually apparent by comparing Figures 7, 8 and 9 where the average number of overweight trucks from either axle or gross vehicle weight limits for each hour throughout the year at each site is displayed. All sites exhibit similar patterns with regard to the increase in overloaded trucks during regular working hours and a decrease during other times. However, the type of overloaded trucks at each site differs substantially. The largest majority of overweight trucks at the Pasco site are double-trailer trucks with few single trailer trucks and

Figure 7. Average number of overloaded trucks for the year, Pasco



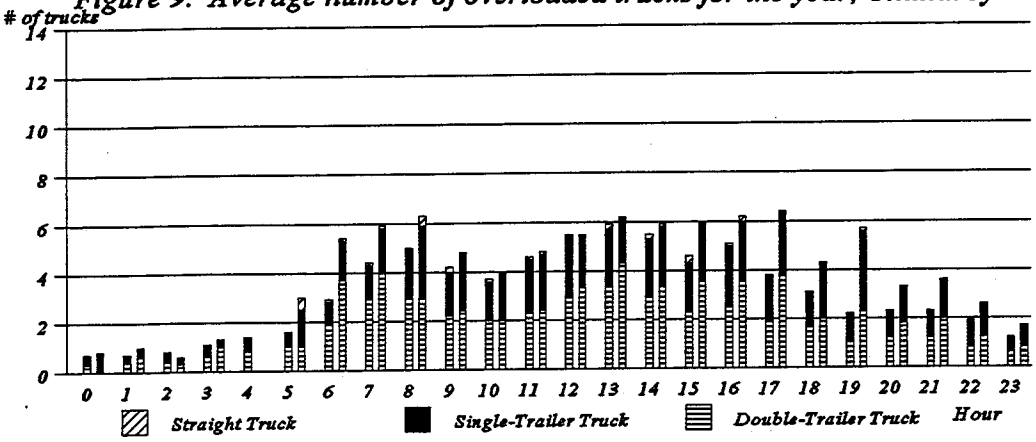
** The first and second column in each hour represents "closed" and "open" weigh station counts respectively.*

Figure 8. Average number of overloaded trucks for the year, Cashmere



** The first and second column in each hour represents "closed" and "open" weigh station counts respectively.*

Figure 9. Average number of overloaded trucks for the year, Chattaroy



** The first and second column in each hour represents "closed" and "open" weigh station counts respectively.*

practically no straight trucks. Cashmere and Chattaroy also have a significant amount of double-trailer trucks as overweight but, proportionately speaking, have a larger number of single-trailer and straight trucks as overweight vehicles. Unfortunately, the distinction between short and long distance trucks cannot be precisely determined from these three different truck configuration types. Generally speaking, however, short distance trucks are typically straight and single-trailer trucks and long distance trucks usually single and double-trailer simply due to the economic and logistical advantages of each type.

After 5:00 pm, there is a larger proportion of long distance trucks on the highway at the Pasco site (Gillis). The economic incentive for these trucks is to maximize their payload, thus decreasing the per unit transportation cost. While these trucks are loaded close to their maximum payload, greater attention is taken to make certain they don't exceed weight limits due to the greater risk and problems associated with being overweight for long distance hauls through several states or countries. Also fewer long distance trucks make return trips empty, simply because of the economic disincentive to do so. Therefore, whenever the Pasco weigh station closes, there is a proportional (but incidental to weigh station operation) decrease in the number of short distance trucks and a proportional increase in the number of long distance trucks, causing the number of overweight trucks to decline while the average gross vehicle and axle weight increases. But, since there are fewer long distance trucks traveling through the Cashmere and Chattaroy sites, the increase in the number of overweight trucks during regular working hours is associated with an increase in vehicle and axle weight.

Average Axle Weight

The average truck axle weight for each hour at all sites is displayed in Figures 10 through 15. Each site's axle weights are reported for "closed" and "open" weigh station hours to allow comparisons of any differences which may exist in axle weights between the two time periods. However, it is quickly evident that very few differences exists in truck axle weights between closed and open weigh station hours for all truck types and for all sites. This could indicate

Figure 10. Average axle weight in kips for the year, Pasco

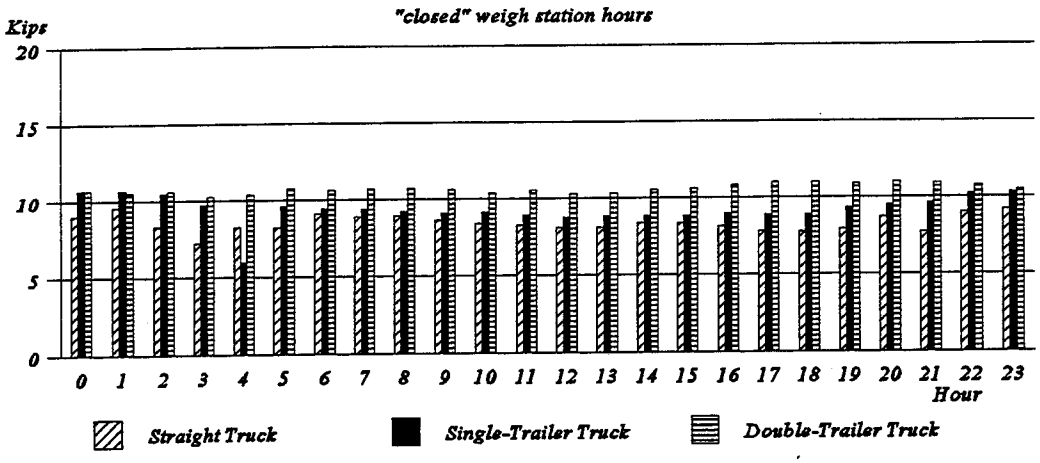
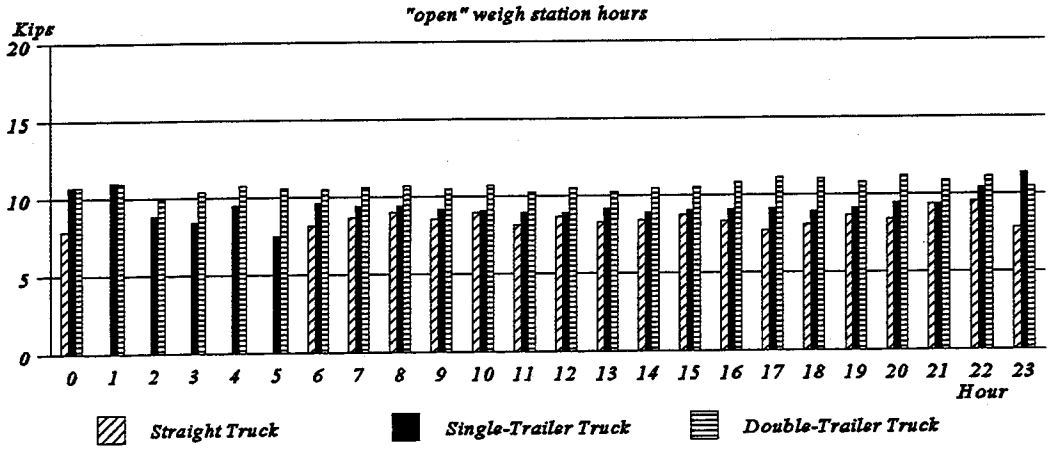


Figure 11. Average axle weight in kips for the year, Pasco



that avoidance activity isn't a substantial problem. There is also little change in the average axle weight throughout the twenty-four hour time period at each site which further suggest that avoidance activity may be minimal.

There are differences in the average axle weight between different sites which are worth mentioning. The average axle weights at the Pasco site are the heaviest of all three sites with double-trailer trucks recording average axle weights around 11 kips for most all hours. Double-trailer trucks at Cashmere and Chattaroy recorded average axle weights well below 10 kips for most hours.

Figure 12. Average axle weight in kips for the year, Cashmere

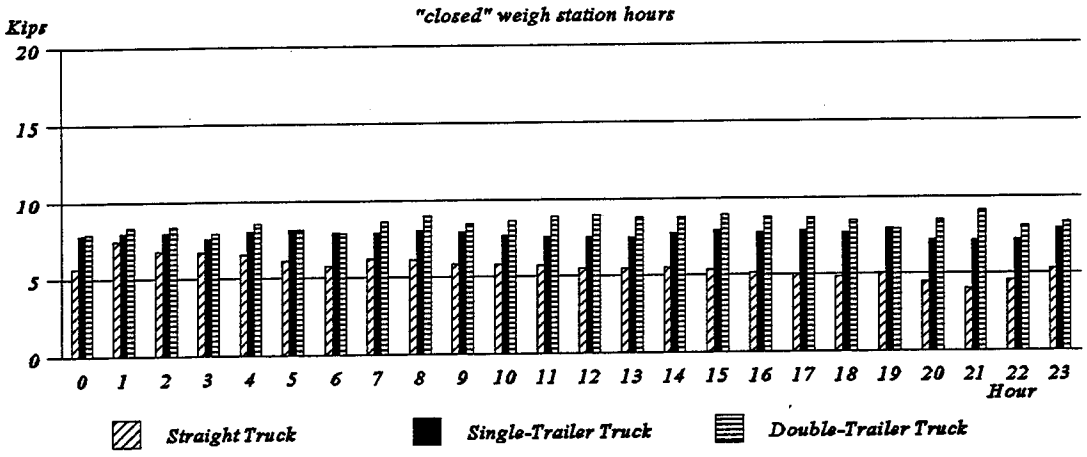
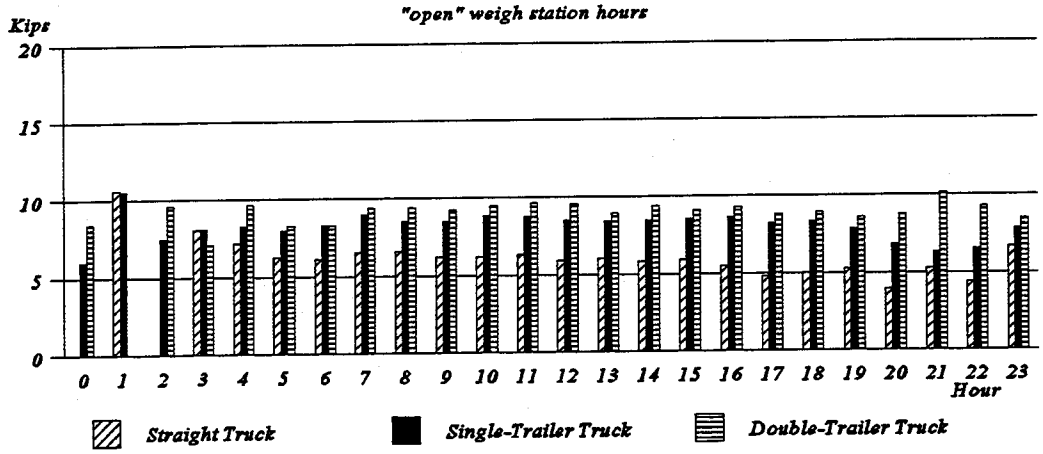


Figure 13. Average axle weight in kips for the year, Cashmere



Double-trailer trucks were the heaviest trucks at all sites and straight trucks the lightest truck type at all locations. Single-trailer trucks have lower axle weights than double-trailer trucks but heavier weights than straight trucks.

Figure 14. Average axle weight in kips for the year, Chattaroy

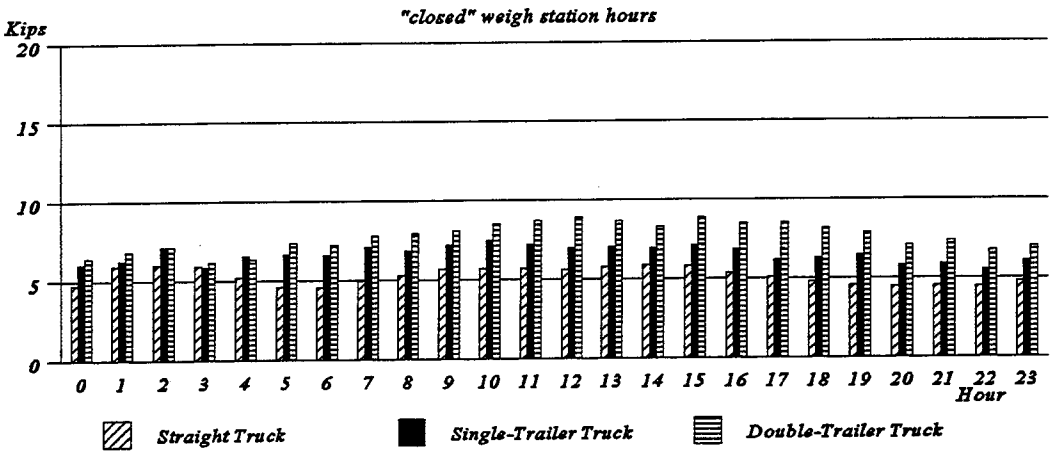
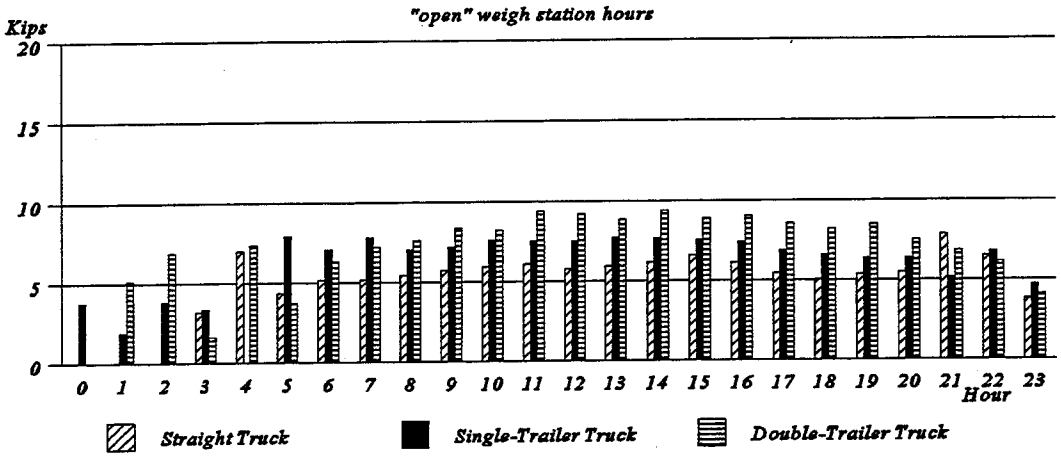


Figure 15. Average axle weight in kips for the year, Chattaroy



Violation and Capture Rate

Any load above the permitted statutory level was considered a violation[1]. The estimated violation rate for open and closed weigh station hours is presented in Figures 16 through 21 for the Pasco, Cashmere and Chattaroy sites. The violation rate for each truck type is not weighted by the number of each truck type in the traffic stream for each hour. Hence, consideration of the proportion of total truck traffic that each truck type represents is necessary for evaluating the reported violation rates. For example, the violation rate for double-trailer trucks is considerably higher for each site than the other two truck types. However, Cashmere and Chattaroy have a very small proportion of double-trailer trucks in the traffic stream, compared to straight and single-trailer trucks. Thus, while it may appear that overweight violations from double-trailer trucks may be a large problem at Cashmere and Chattaroy, the other two truck types are responsible for more overweight violations at these sites when considering the small proportion of double-trailer trucks in the traffic stream. It should also be noted that the high violation rates during the early morning hours are based on 15-20 or less observations during those hours.

The estimated violation rate for the year, weighting each hour by truck volume, was 22% for Pasco and Chattaroy and 20% for Cashmere, indicating that there is a substantial amount of overloaded trucks on the highway. These estimates are at the higher end of the range quoted in previous studies. It is important to remember that these estimates were obtained at three locations and only represent the violation rate at each location. In addition, since in this analysis

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[1] Due to lack of permit information, it is implicitly assumed that all of the loads had purchased permits up to the statutory level (20,000 lbs. on single axles and 34,000 lbs. on any two consecutive sets of tandem axles). To the degree this is not correct, the violation rate is understated. However, some trucks which were classified as "overweight" may have been permitted and operating legally which would tend to overstate the violation rate estimate.

any truck which exceeded its weight limit (on gross or axle), even if only by a few pounds, was considered overweight, these estimates represent a "hard line estimate" on overweight violation.

The violation rate for Pasco increases slightly during regular working hours, mostly due to double-trailer trucks. Since double-trailer trucks are the predominate truck type at this site, a large amount of overweight truck traffic is attributable to this particular truck type, ranging anywhere from 10% to 45% of double-trailer truck traffic.

Figure 16. Violation Rate for the year, Pasco

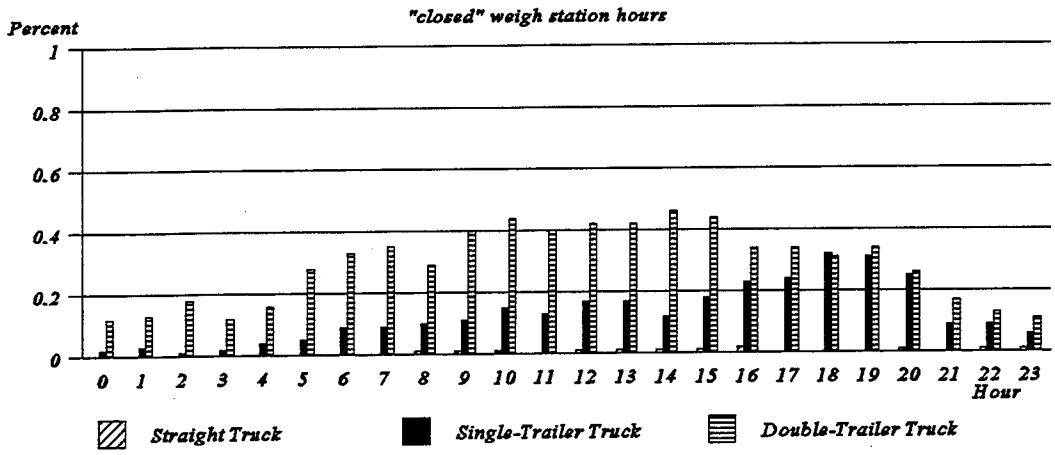
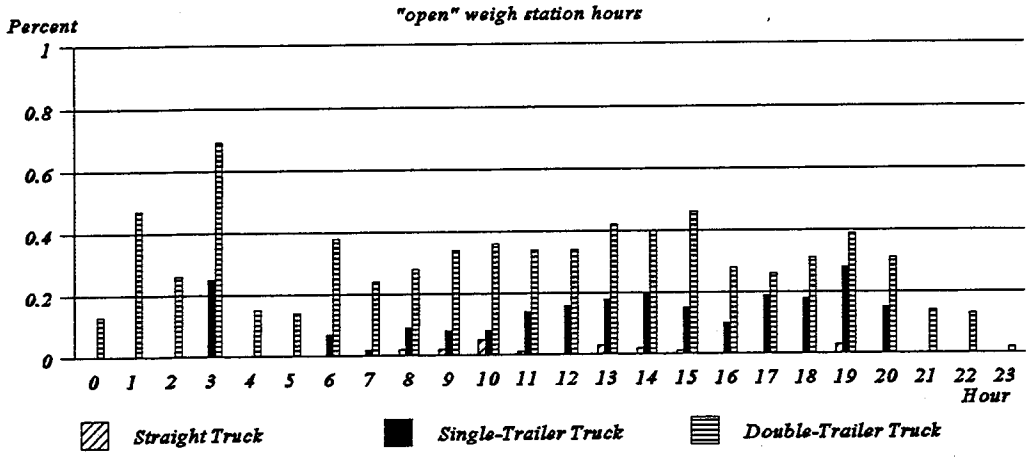


Figure 17. Violation Rate for the year, Pasco



The violation rate for all truck types is considerably higher at Cashmere, especially for single-trailer and double-trailer trucks. However, since the majority of trucks at Cashmere are straight and single-trailer trucks, the total number of overweight double-trailer trucks is quite small relative to the other two truck types. No distinguishable pattern exist for changes in the violation rate throughout the 24 hour time period at this site, indicating that overweight truck violations are fairly evenly balanced for all time periods.

Figure 18. Violation Rate for the year, Cashmere

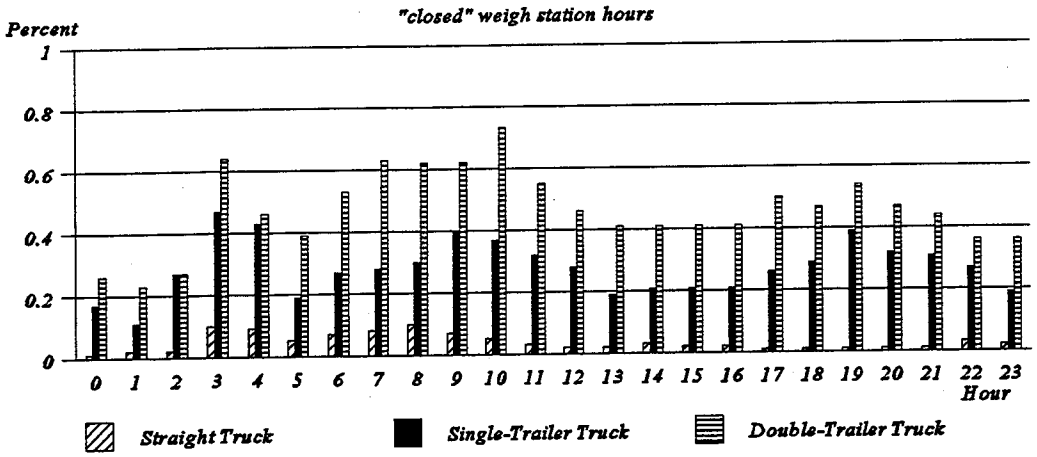
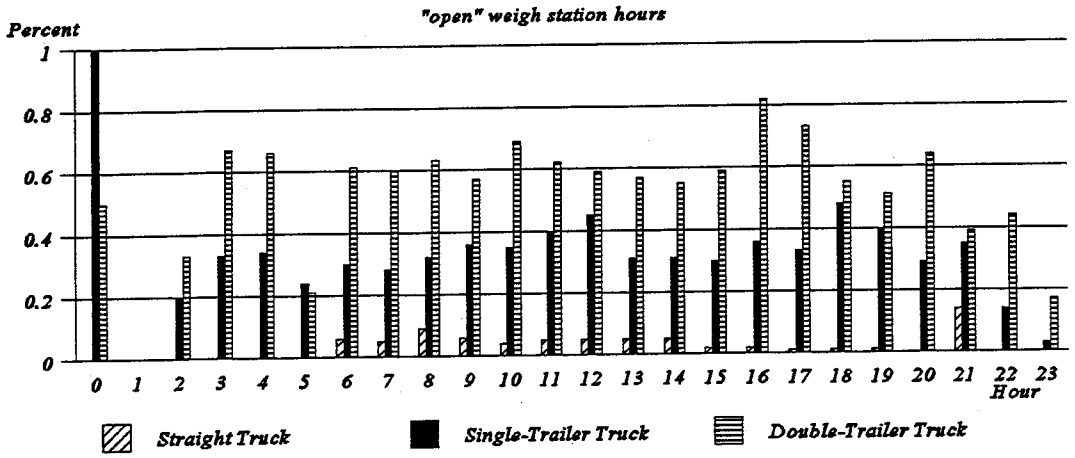


Figure 19. Violation Rate for the year, Cashmere



At Chattaroy, where the predominate truck type is straight and single-trailer trucks, violation rates for straight trucks are extremely low while double-trailer truck rates are quite high. Violation rates for double-trailer trucks also seem constant throughout the 24 hour time period while a definite pattern exists for single-trailer rates which may suggest some avoidance activity with trucks of this type. Violation rates for single-trailer trucks during both closed and open weigh station hours decreases dramatically between 5 a.m. and 6 p.m. Hence, some

Figure 20. Violation Rate for the year, Chattaroy

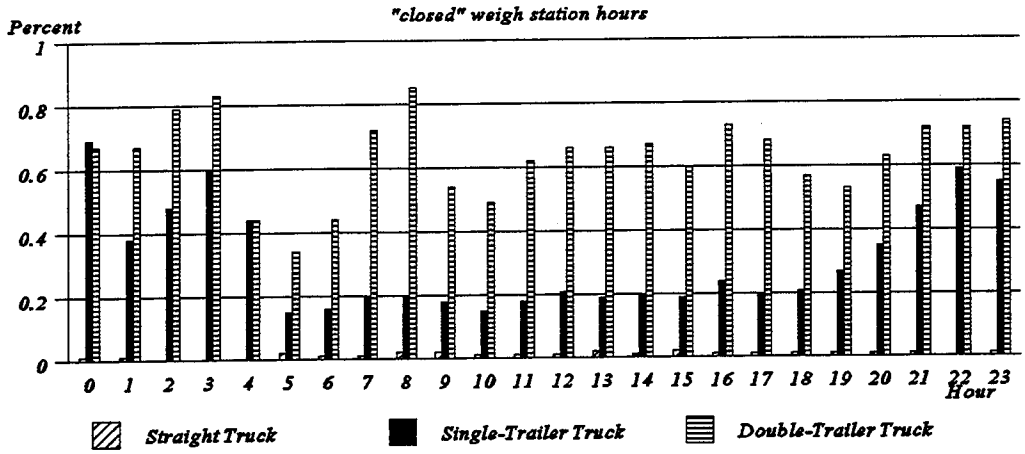
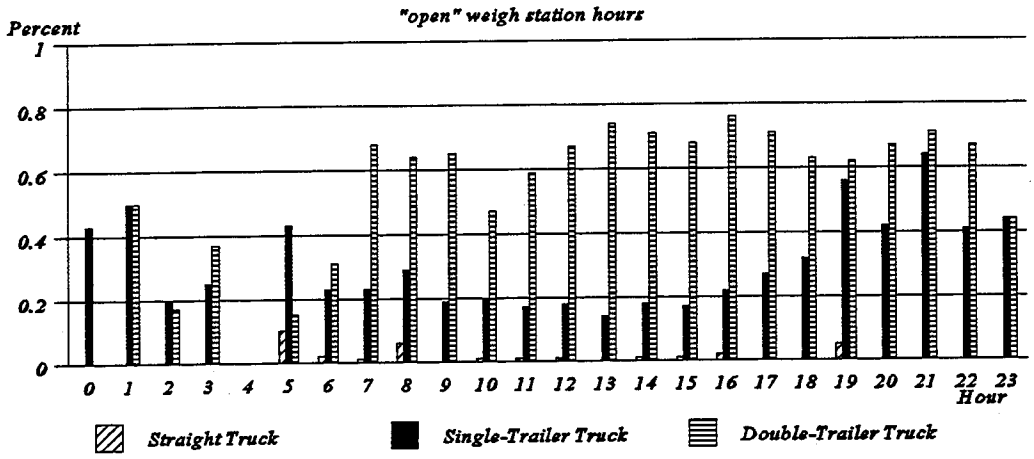


Figure 21. Violation Rate for the year, Chattaroy



overweight single-truck traffic may be waiting until weigh stations close to pass through the Chattaroy site. These results also may indicate a need for enforcement to focus on single-trailer overweight violations given the high violation rates and large proportion of these truck types in the truck traffic at this site.

Capture rates at each site are depicted in Figures 22, 23 and 24 and follow the same general pattern as Figures 3, 4 and 5. Hence, enforcement efforts are directly related to the number of trucks and the average number of overloaded trucks, indicating that enforcement emphasis is effectively targeted during business hours. The low capture rate during non-business hours reflects the fewer hours the weigh station was open relative to the total number of overweight trucks during those time periods. Rates range anywhere from 0% to 62% with an estimated total capture rate for the year of 20%, 27% and 21% at Pasco, Cashmere and Chattaroy, respectively, about double the overall 10% capture rate estimate of Casavant. However, local assembly movements would not appear on these major roads. These estimates suggest that additional enforcement at the Chattaroy site during non-business hours may be appropriate to address higher violation rates. However, this estimate assumes that all overweight trucks which pass through during open weigh station hours are apprehended, which may be somewhat optimistic. Still, enforcement efforts in terms of choosing the appropriate hours of weigh station operation appear quite effective.

Figure 22. Capture Rate for the year, Pasco

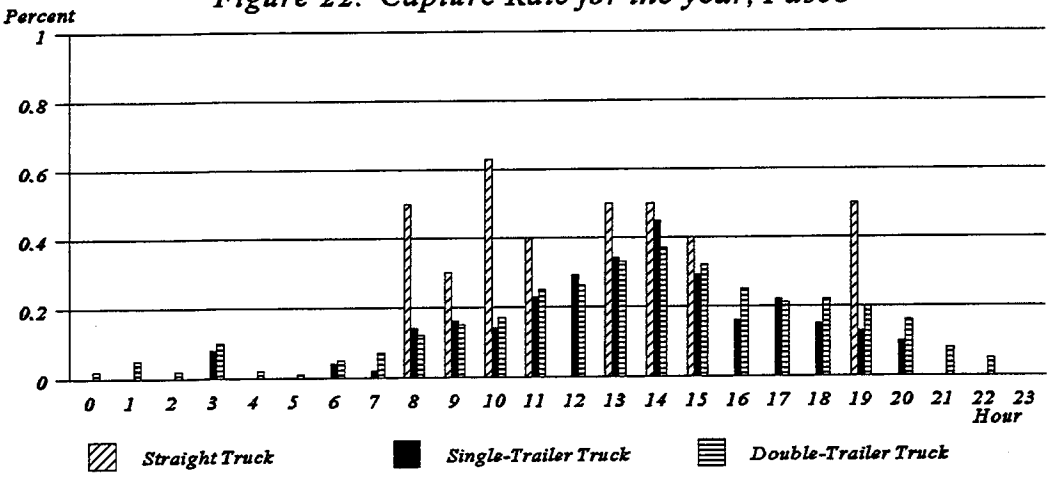


Figure 23. Capture Rate for the year, Cashmere

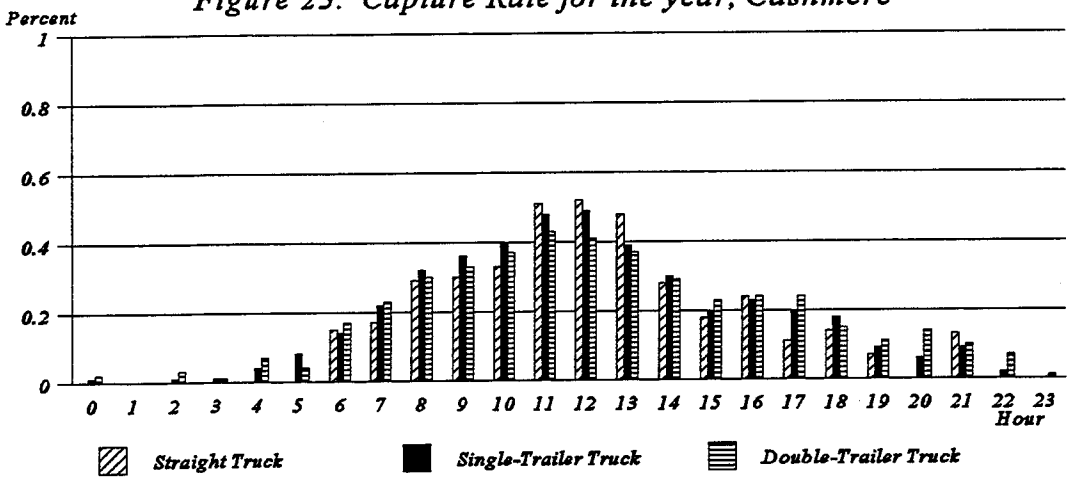
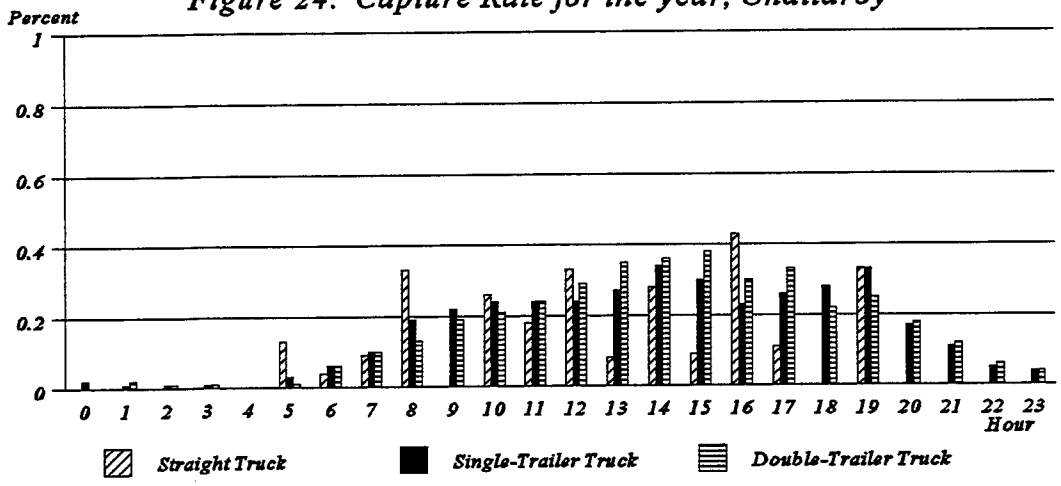


Figure 24. Capture Rate for the year, Chattaroy



Seasonal Analysis

Prior analysis has focused on annual estimates of average number of trucks, overloaded trucks, average axle weights, violation and capture rates for different truck types at three different locations. This section investigates the seasonal changes which affect each of these variables for each study area.

The figures for the seasonal analysis are grouped into four categories representing spring, summer, fall and winter and are provided in detail in Appendix A. Only general findings are discussed in this section. The title postfix on each figure indicates the season which the figure represents. For example, Figures 1sp, 1su, 1f, and 1w represents the average number of trucks for Pasco during the spring, summer, fall and winter, respectively.

Pasco

There is some variation in the average number of trucks passing through the Pasco site for each season, as depicted in Figures 1sp, 1su, 1f and 1w . The season with the heaviest truck traffic at this site is summer with all other seasons experiencing similar truck traffic flows. All seasons except summer also have a similar composition of truck types with double-trailer trucks comprising the majority of trucks, followed by single-trailer and straight trucks, respectively. During summer, however, the proportion of straight and single-trailer trucks outweighs the proportion of double-trailer trucks, especially during the hours between 8:00 a.m. and 5:00 p.m. This could reflect the increase in truck traffic associated with milder weather such as construction activities and local agricultural production.

There is considerably more variation in the average number of overweight trucks across

seasons, as illustrated in Figures 4sp, 4su, 4f and 4w. The average number of overweight trucks increases dramatically during summer and fall, consisting of mostly single and double trailer trucks. Very few overloaded trucks are present during winter at this site as witnessed by the average number of overweight trucks being less than 5 for all hours. Double-trailer trucks represent the largest proportion of overweight trucks for all seasons with single-trailer trucks representing the second largest proportion and very few overloaded straight trucks.

Comparison of the average axle weights for trucks at the Pasco site reveal little variation in axle weights across season, for different hours of the day, and between "open" and "closed" weigh station hours. For all seasons and hours of the day the average axle weights range between 8 to 10 kips with double-trailer trucks recording the heaviest axle weights, followed by single-axle and straight trucks. This pattern is consistent for all seasons and hours, as displayed in Figures 7sp, 8sp, 7su, 8su, 7f, 8f, 7w, and 8w.

Changes in the violation rate at Pasco are illustrated in Figures 13sp, 14sp, 13su, 14su, 13f, 14f, 13w and 14w, and follow a very similar pattern as the average number of overweight trucks mentioned previously. Specifically, the seasons with the highest violation rate are the same seasons which experienced the largest average number of overweight trucks; summer and fall. The violation rate for these seasons reach as high as 70% during certain hours, which is a fairly high proportion of truck traffic consisting of mostly single and double-trailer trucks. The violation rate during winter is considerably lower, remaining under 20% for all hours. Hence, summer and fall are seasons with high violation rates with the most frequent truck type being single-trailer and double-trailer trucks.

After identifying the seasonal changes in the violation rate, it is interesting to evaluate the

capture rate, relative to changes in the violation rate. Interestingly, the capture rate, as displayed in Figures 19sp, 19su, 19f and 19w, follows a similar pattern as the violation rate. The two seasons summer and fall, which have the highest violation rates, also have the highest capture rates with winter having the lowest of both rates. However, the type of trucks which have the highest violation rate are not the type of trucks with the highest capture rate. Double-trailer and single-trailer trucks were the predominate overweight trucks whereas straight and single-trailer trucks have the highest capture rates. This relationship is reflective of the corresponding increase in short distance truck traffic (straight and single-trailer trucks) associated with regular working hours which is also the time period when most weigh stations are in operation. This could have implications concerning enforcement strategies and where efforts would be most effectively targeted.

Cashmere

The average truck volume for Cashmere follows a slightly different pattern than Pasco, in terms of seasonal volume and truck type composition. Specifically, summer and fall both have relatively larger average truck volumes than spring and winter, which is apparent by comparing Figures 2sp, 2su, 2f and 2w. The predominate truck type in the traffic stream for all seasons at Cashmere is straight trucks followed by single-trailer and double-trailer trucks, unlike Pasco truck traffic. The relatively larger proportion of straight and single-trailer trucks reflects the different operating environment and highway usage of the Cashmere site which is consistent with the annual analysis.

The average number of overweight trucks at Cashmere is fairly consistent during spring,

summer and winter, ranging in the neighborhood of 10 trucks per hour or less. However, the average number of overweight trucks increases substantially during the fall to almost 25 trucks per hour for hours 9 through 13. Single-trailer trucks comprise the largest percentage of overweight trucks for all seasons with straight trucks representing the lowest proportion of overweight truck traffic, as illustrated in Figures 5sp, 5su, 5f and 5w. However, the large total volume of overweight trucks during fall, in addition to the truck type composition, could be reflective of the truck traffic generated by farm production harvest.

Average axle weights for Cashmere are slightly lower than Pasco, but are consistent for all seasons and hours, indicating very little variation in truck weights throughout the year. Axle weights for this site are generally in the neighborhood of 5 to 10 kips (Figures 9sp, 10sp, 9su, 10su, 9f, 10f, 9w and 10w). Double-trailer trucks also record the heaviest axle weights, followed by single-trailer and straight trucks, respectively.

Though considerably less truck traffic appears at the Cashmere site when compared to Pasco, the violation rate for all trucks at Cashmere is considerably higher for all seasons. The highest violation rates occur with double-trailer and single-trailer trucks at this site. However, given the small proportion of double-trailer trucks in the traffic stream, the high violation rate for double-trailer trucks isn't as significant as the violation rate for single-trailer and straight trucks. A comparison of Figures 15sp, 16sp, 15su, 16su, 15f, 16f, 15w and 16w reveals the season with the highest violation rates is fall while summer has the lowest rates.

The capture rates for each season at Cashmere are provided in Figures 20sp, 20su, 20f and 20w. Capture rates for all seasons increase significantly during regular working hours and decrease substantially during non-business hours, reflecting the truck traffic pattern for all truck

types and the enforcement efforts designed for these flow patterns. As with the Pasco site, capture rates for straight and single-trailer trucks are generally higher than capture rates for double-trailer trucks. This is interesting because the highest violation rates from both sites are from double-trailer trucks. There is little variation in the capture rates for all truck types across seasons, however, spring capture rates are slightly higher than the other three seasons at this site. Hence, enforcement efforts appear equally effective for all seasons at Cashmere.

Chattaroy

This particular site has the lowest truck traffic volume of the three selected sites for all seasons. However, the truck traffic patterns displayed at this site are similar to those experienced at Cashmere in some respects. First, straight and single-trailer trucks comprise the predominate truck type at this location for all seasons as at Cashmere (Figures 3sp, 3su, 3f and 3w). Double-trailer trucks represent a very small percentage of truck traffic for all seasons, indicating that long distance trucks are not as prevalent at this location as Pasco. Also, truck volume is positively related to regular business hours as indicated by the significant truck traffic increase during the hours of 8:00 a.m. to 5:00 p.m. The season with the highest truck traffic volume is summer. Fall and winter have the lowest truck volumes with approximately 20 to 30 trucks per hour during business hours.

Unlike the other locations, the average number of overweight trucks at Chattaroy is very consistent for all hours and seasons. There is little variation in the average number of overweight trucks which is generally around 5 trucks per hour. Also, the composition of truck type for overweight vehicles at this site is quite different from Cashmere, but similar to Pasco. Double-

trailer trucks constitute the majority of overweight vehicles for all seasons, which is significant given the small proportion of total truck traffic double-trailer trucks represent at this location. The consistency and truck type composition of overweight vehicles is evident by evaluating Figures 6sp, 6su, 6f and 6w.

The consistency with the average number of overweight vehicles for each hour and season also carries through to the average axle weights for each season at Chattaroy, as depicted in Figures 11sp, 12sp, 11su, 12su, 11f, 12f, 11w and 12w. Average axle weights for all seasons are generally between 5 and 10 kips, with very little variation across hours. Also, the heaviest axle weights are from double-trailer trucks followed by single-trailer and straight trucks, respectively. This same pattern exists at all locations.

Evaluation of the violation rates displayed in Figures 17sp, 18sp, 17su, 18su, 17f, 18f, 17w and 18w may indicate some avoidance activity, specifically with single-trailer trucks. Violation rates for all seasons are considerably higher for double-trailer trucks than single-trailer trucks with violation rates for straight trucks being practically insignificant. The violation rate for straight trucks and double-trailer trucks does not exhibit any distinguishable pattern during the 24 hour time period, across seasons. However, single-trailer trucks have higher violation rates during non-business operating hours, which is also the time period which the weigh station is usually closed. This pattern is consistent, and quite dramatic, for all seasons suggesting that weigh station avoidance may be a significant problem at this location for single-trailer trucks. While most seasons appear similar in terms of the violation rate for different truck types, the violation rates during summer may be slightly lower than other seasons.

Capture rates for Chattaroy increase during business hours and decrease during non-

business hours, as with the other sites. Also, capture rates are quite high for straight trucks relative to the low violation rates from this truck type. Capture rates for all truck types generally range between 10% and 25% for all seasons at this location which is illustrated in Figures 21sp, 21su, 21f and 21w. Comparison of the violation and capture rates at this location may imply a need to direct enforcement efforts toward more non-business hours given the large violation rates and low capture rates during those time periods.

Site Comparisons

Evaluation of the changes which occur during the seasons at each site allows the identification of seasonal influence on truck volume, overweight truck volume, axle weight, violation and capture rates. However, it is also useful to identify any similarities and differences which occur at each site for these same variables.

The truck volume at each site generally increases and decreases over the 24 hour time period in the same fashion for each season. Between the hours 8:00 a.m. and 5:00 p.m. there is a distinguishable increase in the truck volume at all sites and an associated decrease in truck volume outside this time window. This is not surprising since we expect truck traffic to increase as businesses open and engage in their daily activities requiring transport. However, the composition of truck traffic differs substantially at each site and remains different for all seasons. Truck traffic at Pasco is predominately single-trailer and double-trailer trucks with very few straight trucks in the traffic stream. The truck traffic at Cashmere and Chattaroy is comprised of mostly straight and single-trailer trucks, suggesting a lower number of long distance trucks at these sites.

The summer season for each site generally has the largest truck volume of any season

reflecting the increase in business activities associated with this time period. The season with the lowest truck volume varies by site with no clear seasonal pattern.

Changes in the number of overloaded trucks at each site follows a similar pattern as the total truck volume at each site and for each season. The composition of overloaded trucks at the Pasco and Chattaroy sites is predominately double-trailer and single-trailer trucks whereas overloaded truck traffic at Cashmere is mostly single-trailer and straight truck. The season with the largest number of overloaded trucks varies by location and is influenced by the characteristic associated at each site. Pasco and Cashmere have the highest number of overloaded trucks during the fall (reflective of agricultural harvest) while overweight truck numbers reach their maximum during spring for Chattaroy (logs and forest products harvest). There also appears to be considerably more seasonal variation in the average number of overloaded trucks for Pasco and Cashmere. The average number of overweight trucks is fairly constant for the different seasons at Chattaroy.

Axle weights vary slightly for the three different locations, with Pasco recording the heaviest axle weights, ranging between 8 and 11 kips. Axle weights at Chattaroy and Cashmere are very similar, usually weighing between 5 and 10 kips with little variation over the 24 hour time period. One consistency for each site and all seasons is the type of truck with the heaviest axle weights. Double-trailer trucks generally recorded the heaviest axle weights for all sites, seasons, and hours with single-trailer and straight trucks following, respectively.

Violation rates for the different truck types are similar to the axle weight patterns for different truck types. Double-trailer trucks have the highest violation rates for all locations and seasons, followed by single-trailer and straight trucks. The season with the lowest violation rates

varies by location. The lowest violation rates for all truck types at Pasco is during winter, whereas summer appears to be the season with the lowest violation rates at Chattaroy and Cashmere. There also is substantial variation in the violation rate over the 24 hour time period for all locations and seasons.

Capture rates for each location increase during regular business hours and decrease during other times, reflecting the hours which most weigh station are open and enforcing truck weight limits. This pattern is consistent for all sites and seasons. The truck type with the highest capture rates varies significantly for different hours, with no clear seasonal pattern or site comparison. However, capture rates for straight trucks are relatively high compared to the other truck types and the relatively low violation rates observed by straight trucks. This may indicate greater effectiveness with enforcement of weight limits on straight trucks relative to the other truck types.

CONCLUSIONS AND IMPLICATIONS

This study has helped define the nature and influences of truck movement characteristics on overweight truck violation, in addition to empirically estimating violation and capture rates for different truck types, different seasons, and for all hours throughout the day. Occurrence of overweight vehicles on the highway and any avoidance activity associated which these overweight vehicles are predominately driven by business forces. The economic activity (demand for transportation) generated during the regular working hours directly impacts the number of trucks on the highway, the proportion of those trucks which are overweight and the average vehicle and axle weight. Exactly how this business and economic activity impacts each of these variables depends largely on the types of businesses creating the truck traffic, which also determines the