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TRUCK LANE AND AXLE LOAD DISTRIBUTION ON MULTILANE RURAL HIGHWAYS IN ALBERTA

BY

JOSEPH K. AMANIE BERVELL

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DEDICATION

To my Dearest Wife and Mother

Abstract

Accurate determination of loadings on multilane highway lanes is one principal means of ensuring an adequate pavement thickness for highway traffic. On the existing pavement system, the number and magnitude of vehicular axle-loads can have an adverse effect in the form of premature damage and reduction in service life, with consequent increases in the costs of pavement upkeep.

The unequal distribution of heavy vehicle axles across the highway lanes requires that the loading in the lane used for design is accurately assessed. Also, within the vicinity of intersections with a high proportion of turning truck movements, the choice of lanes by trucks on turning may influence the loading in the lanes and hence the selection of the design lane.

Trucks in the traffic stream affect the operation characteristics of other vehicles. At unsignalized intersections, incidents such as the forced use of the highway shoulders by trucks, queue formations on the main highway and other incidents may occur on turning.

Two years of collected traffic volume and vehicle weight data at a rural weigh-in-motion site in central Alberta and a field survey of turning trucks at an intersection were used to study the loading impacts in the

lanes of a multilane highway. An assessment is also made of the loading impact of the RTAC vehicle weight changes in 1988 and changes in truck axle configuration.

The impact of heavy vehicles on traffic operations, safety and pavement performance is reviewed, but the focus of the thesis is on the truck traffic load demand on the highway as regards to thickness design of the pavement.

The findings of the thesis will be beneficial to the economic design of highway pavements and their maintenance and for assessing the degree of overloading on the highway.

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CHAPTER 1

INTRODUCTION

1.1. Background

There are several factors which enter into the determination of the thickness of a highway pavement structure. Among these are the expected traffic loading on the pavement structure, soil conditions, environmental conditions, physical properties of the particular pavement type, and others.

In determining the expected traffic loading on the pavement structure, the prime considerations are the number of trucks and the magnitude and repetitions of axle loadings. Traffic loading consists of numerous passes of various vehicle types, usually classified according to axle configuration, in a highway lane within a selected traffic analysis period (20 years is often used). The principal truck types considered are the large tractor-semitrailer combination types, which will be using the facility during its service life because they contribute almost exclusively to the accumulated loading. Cars, although usually numerically greater in proportion to trucks, contribute little to loading because of their very light weight. In many instances cars and similar type vehicles, such as recreation vehicles, pickup and panel trucks, are not considered at all since the larger trucks make up the entire loading factor.

On multilane facilities it is recognized that not all trucks use the same lane in travelling; therefore, the pavement structure should not be designed for total trucks but for only those using the heaviest traveled truck lane. The problem here is in determining for each design situation what percent of the total loading and truck traffic is on the lane used by heavy trucks. Until recent years, an estimate for this value called the Lane Distribution Factor was made based on short period traffic counts in lanes and engineering judgement. If a more accurate assessment of the lane distribution of truck loading is to be determined on a highway facility, it would be necessary to make more accurate loading predictions. Thus, more accurate determinations could then be made in the thickness of pavement needed. At today's construction costs, the savings from a reduction in pavement thickness on a multilane facility could be considerable.

Motivated by concern for protecting pavements from the effects of heavy loads, Highway Agencies recommend limits on the weights of truck categories. Changes in truck weight limits can affect the cost of maintaining the condition of the highway pavement and safety margins of bridges. Truck weight changes also affect the number of accidents, highway congestion and traffic operations. These occur as a direct result of increase or decrease in the amount of truck traffic on the highway after weight change legislations.

1.2. Need for Research

In order to optimize the planning, design, construction and maintenance of existing and future highway facilities, the accurate estimation of truck number and axle load distribution across multilane highway lanes should be known. The foregoing background calls for the need to address this issue.

1.3. Research Objectives

This thesis report details the analysis of traffic data obtained from a weigh-in-motion (WIM) scale installed on a four-lane primary highway in central Alberta. Traffic data collected before and shortly after the implementation of the recommended changes in vehicle weights by the Road and Transportation Association of Canada [(RTAC, now the Transportation Association of Canada (TAC)] in 1988 are used for the analysis.

A field survey on the lane choice pattern of turning trucks at an unsignalized intersection is also used to discuss lane choice patterns of left-turn truck traffic on multilane highways.

Specific objectives considered in the study are as follows:

1. To develop representative lane distribution factors for trucks in the province from recorded WIM scale data. The

resulting proportions are compared with distribution factors reported in the literature and in current practice.

2. To analyze the equivalent single axle load (ESAL) factors generated by truck types in lanes, and also the seasonal variation in both ESAL factors and loading trends.

3. To assess changes in truck axle configuration and axle load distribution after the recommended changes in vehicle weights and dimensions by the Road and Transportation Association of Canada (RTAC), in 1988.

4. To evaluate the projected impact of the RTAC vehicle weight and dimension changes on pavement structure requirements on major highways in Alberta.

5. To study the operational impact of left-turning trucks at a particular unsignalized intersection and also determine the lane choice behavior during the left-turn maneuver.

1.4. Scope Of Research

In organizing the research project, a number of activities were defined which dictated the course of action needed to meet the research objectives. The following, were taken into consideration to limit the research to a manageable level.

- The study is based on a single site WIM scale located on a four-lane rural highway near Edmonton. Truck loading data collection using WIM scales on six or more lane rural highways in the province has not yet been established.
- The study utilizes classification of vehicles by Alberta Transportation and Utilities procedures and is restricted to truck types classified on Alberta's highway system and their weighed axles. Trucks as defined in this study include all vehicles of the single unit, tractor semi-trailer and combination trailer types. Heavy trucks are considered as tractor semitrailer combination types of five or more axles.
- The assessment of left-turning truck traffic behavior and operations are based on the study of a single intersection. Data collected during three days of field survey at the intersection served as the basis for the discussions and conclusions.

1.5. General Organization of Thesis

Chapter 1 gives an introductory overview of the thesis study. The need for the research and outlined objectives to meet the needs are given.

In Chapter 2, a review of the literature on the influence of heavy vehicles on the highway is presented.

Reviewed aspects of trucks include lane distribution and the equivalent single axle load (ESAL) concept. The allowable weight limits of vehicles as recommended by RTAC in 1988 and weigh scales are also reviewed. A brief review of truck operations, particularly at unsignalized intersections is made. This chapter is intended as a perspective introduction to the subsequent chapters dealing with the analysis of truck lane and axle load distribution.

Data collected automatically on vehicle number, truck gross weight and axle load at the Leduc WIM site are the source of data for the analysis in Chapters 3, 4 and 5.

In Chapter 3, presentation of the Leduc WIM scale data and traffic volumes at the site are analyzed. Two sets of traffic volume data obtained, one from the year of 1986 and one from the year of 1989 representing test data prior to and after the 1988 recommended changes in vehicle weight and dimensions are used. As a preview to the traffic loading analysis in Chapter 4, data tables on truck mix, the hourly, daily and seasonal fluctuations in traffic volumes are presented.

Chapter 4 documents the gross vehicle weight and axle load distribution from the WIM scale. Generated equivalent single axle loads (ESALs) and ESAL factors of truck types are analyzed by week and season.

In Chapter 5, pavement thickness design analyses using the analyzed truck axle load distribution and generated ESAL results from Chapters 3 and 4 are presented. An assessment is made of the impact of the RTAC truck weight changes on pavement structural thickness requirements. Truck loading parameters, with 1986 and 1989 as base years, are projected for 20 years to determine comparative flexible and rigid pavement thicknesses. A micro-computer program for designing concrete pavements, is used in analyzing changes in rigid pavement thickness (PCA 1985). For flexible pavement thickness consideration, a full depth asphalt thickness design using the Asphalt Institute procedure is utilized.

Chapter 6 deals with some operational aspects of left-turning trucks at a major unsignalized intersection and their influence on main highway traffic. The lane choice behavior of left-turning trucks with through traffic flow rates is assessed. A documentation of the manual survey method used in this study is discussed in detail.

A general summary, conclusions and recommendations of the study are presented in Chapter 7. Recommendations for future research work on vehicle loading which would contribute to the economic design of pavements, efficient use of existing highway facilities and improvements in truck operations and safety on roads are made.

The appendices contain sample printout of WIM data and the output from the rigid pavement computer program, PCAPAV.

CHAPTER 2

HEAVY VEHICLES ON THE HIGHWAY

2.1. Introduction

Truck lane use and gross vehicle weights vary from one segment of highway section or highway jurisdiction to another across North America. The proportion of truck volume and gross weights on each lane of multilane highways have impacts on the deterioration rate of highway pavements, traffic operations and safety. Pavement deterioration increases with axle weight and with the repetitive nature of axle loadings to which the pavement is subjected.

Unequal distribution of truck volume and loading on the highway lanes results in a significantly different cumulative traffic loading for each lane of a multilane highway. For the purposes of economic design of highway pavement thicknesses, the traffic loadings in the lane controlling the design should be determined and considered.

2.2. Highway Loadings

The service lives of pavements and bridge structures are largely affected by a variety of factors acting both independently and in combination. Among the factors, traffic component has the greatest effect on pavement deterioration. Traffic characteristics include the total gross vehicle weight (GVW), axle configuration, weight distribution on axles, traffic volumes and traffic mix (TRB Special Report 211, 1986, p.159).

Large trucks contribute the greater proportion of accumulated highway loadings. There has been an annual increase in the number of large trucks and size of loads which adds to the increasing deterioration of pavement facilities (Statistics Canada, 1987). The increasing trend in truck proportions is due mostly to advances in motor vehicle technology and the economics of freight transportation which favour the highway transportation mode. Trucks have also dominated in the movement of goods because of the flexibility of trucking and a well maintained and developed highway network.

The loading impact of truck axles is translated into equivalent single-axle loads (ESALs). An estimated pavement thickness to support cumulative truck loadings is based on the individual ESAL factors and the occupancy of truck traffic in the design lane during the service life of the pavement.

2.2.1. ESAL Concept

The concept of an equivalent single-axle load (ESAL) is used by pavement engineers to evaluate the effect of changes in vehicle size and axle weight on pavement deterioration. Expressions developed from the AASHO Road Test (HRB, 1962) allow the conversion of projected axle loads from different vehicle configurations into equivalent loadings. Conventionally, an 18-kip (80 kN) single axle is 1.0 ESAL. The ESAL values for other axles express their relative effect on pavement damage.

Load equivalence factors vary sharply with the magnitude of weight, following roughly a fourth-power relationship. This is illustrated in Figure 2.1. ESAL factors increase approximately as a function of the ratio of a measured axle load to the standard 18-kip (80-kN) single axle load to a fourth power. This can be expressed as:

$$F = \left(\frac{W_i}{W_s}\right)^4$$

where F is the equivalency factor.

Wi is the specific load applied

Ws is the standard axle load

To illustrate the concept, the load equivalence factor for a 20-kip single axle is about 1.5 because $(20/18)^4$ is approximately equal to 1.5 on both flexible and rigid pavements. Thus 100 passes across a pavement by a 20-kip axle would have the same effect on pavement life as 150 passes by an 18-kip axle.

AASHTO provides separate sets of ESAL values for flexible and rigid pavements. The principal difference between the flexible and rigid pavement ESAL values is that tandem axles have greater loading effect on rigid pavements (see Figure 2.1). For example, a 34-kip tandem axle is about 1.1 ESALs on flexible pavements and about 2.0 ESALs on rigid pavements.

2.2.1.1. AASHO Equivalency Factors

The ESAL concept dates back from the statistical analysis of the American Association of State Highway Officials (AASHO, now AASHTO) Road Test data conducted in the late 1950's. It was found in these tests that the generated ESAL is a function of pavement type and of the level of damage which is described by a present serviceability index (PSI). The PSI is particularly influenced by the roughness of the pavement. In the AASHO test sets of ESAL values for single and tandem axles on both flexible and rigid pavements were given (HRB 1962).

In 1986 the Road test results were extended by the American Association of State Highway and Transportation Officials (AASHTO) to provide load-equivalence factors for tridem axles on rigid pavements (AASHTO, 1986). The current AASHTO Guide also presents tables of equivalency factors for different terminal PSI values. ESAL factors for PSI of 2.0, 2.5, and 3.0 for flexible and rigid pavements as well as single and tandem axles are given.

The developed relationship between the number of applications of an 18-kip (80-kN) single axle load (standard axle) and the number of applications of any axle load, single or tandem, to cause the same potential damage can be determined from the following simplified equivalency equations:

For rigid pavement as:

$$R_{18} = \frac{(L_1+L_2)^{4.62}}{808,800(L_2)^{3.28}}$$

For flexible pavement:

$$R_{18} = \frac{(L_1+L_2)^{4.79}}{1,334,000(L_2)^{4.33}}$$

in which

R_{18} = Number of 18-kip single-axle loads equivalent to the axle load (L_1) in question;

L_1 = Nominal axle load (single or tandem), in kips;

and

L_2 = 1 for single axles, 2 for tandem axles. (HRB 1962)

2.2.1.2. **ESAL Estimation at WIM scale**

Recent progress in weigh-in-motion (WIM) technology has made WIM scales suitable for continuous axle load data recording and ESAL factor estimation (RTAC 1981; Bergan 1978). At WIM scale sites, ESAL factors for individual vehicles are converted from recorded axle loads using the ESAL versus axle load relationships of the AASHO road test or the relationships proposed by the Asphalt Institute (Haas 1978, p. 161). These expressions are incorporated in the scale's computer system which allows an instantaneous computation and recording of the estimated ESAL. Daily ESAL repetitions are calculated by summing ESAL factors of individual vehicles. WIM scales categorize group of axles passing as single, tandem or tridem axles depending on the detected distance between the centers of two or three successive axles. Incorporated equivalency expressions are automatically applied to axle load groups to determine the ESAL factors.

At the Leduc WIM site in central Alberta, the AASHO equivalency factor expressions for flexible pavements and a modification of these expressions to account for single and tandem steering axle weights are used. The expressions used for the ESAL factor conversion at this scale are given by Lowe et al. (1983), as follows:

For Single steering axles: $N_{18} = (L/11.5)^{3.30}$

For Tandem steering axles: $N_{18} = (L/28)^{3.30}$

For Single and Tandem carrying axles:

$$N_{18} = \frac{(L+L_2)^{4.79}}{1.334 \times 10^6 \times (L_2)^{4.33}}$$

$L_2 = 1$ for single axles and 2 for tandem axles

For Tridem Carrying axles: $N_{18} = (L/47)^{4.49}$

All axle weights (L) are expressed in lbs x 10^{-3} (kips)

Mixed Imperial and SI units are presented in the WIM scale data. ESAL values are presented in terms of 18-kip ESALs while axle loads and dimensions are in tonnes and metres respectively.

2.3. Highway Loading Studies in Alberta

Previous analyses on truck traffic loading demand in Alberta have been based on one day detailed surveys of truck axle weights. Such single day survey data have been examined by Shields and Wagner (1976, 1978) and by Christison and Krumins (1983). The surveys are conducted annually by Planning Services, Alberta Transportation and Utilities at selected sites within the province.

In the 1976 analyses by Shields, truck axle weights before and after increased load allowances authorized in August 1974 were examined. The results indicated that the average ESAL factor of truck traffic increased by about 16 percent immediately after increased load allowances. A similar analysis on 1977 loading data showed a 78 percent increase over "before" 1974 loading. A significant shift to the use of more truck-trailer and combination units in the traffic stream was observed and reported (Shields and Wagner, 1978).

2.4. Lane Distribution Factors

Although many traffic and geometric conditions affect the lane distribution of trucks to varying degrees, traffic volume has been reported to be the most significant single factor in determining which lane trucks will travel in. An increase in traffic volume will tend to decrease the percent of total trucks using the heaviest traveled truck lane (Darter et al., 1985; PCA, 1984).

2.4.1. AASHTO Distribution Factors

The 1986 AASHTO pavement design guide contains guidelines on the percent of 18-kip (80-kN) ESAL traffic that uses the design lane of a highway network. The recommended values for the lane distribution factors are shown in Table 2.1. As indicated, the AASHTO recommendation suggests that the proportion of equivalent truck loading in the design lane depends on the number of lanes on the multilane highway. The lane distribution factors, range from 100 percent for 2-lane highways to between 50-75 percent for highways with eight or more lanes.

Various agencies and highway jurisdictions which have no detailed information on the distribution pattern of trucks across lanes in their jurisdiction may use the AASHTO distribution factors. However, the level of truck volumes, buses, and passenger vehicle activities in a particular region is known to influence these factors.

2.4.2. NCHRP Report 277 Lane Distribution Factors

In a study undertaken under the National Cooperative Highway Research Program (NCHRP), traffic data from more than 120 locations in six states of the United States were used to derive expressions on truck lane distribution factors. The results is reported in NCHRP Report 277, "Portland Cement Concrete Pavement Evaluation System (COPES)" (Darter et al, 1985). In this report, predictive equations are developed for the proportion of trucks in each lane of highway facilities with four or more lanes. These proportions are found to be based on the one way traffic volume at a particular site. The lane distribution equations are stated from pages 51 and 52 of NCHRP report 277 as follows:

1. Proportion of all one-directional trucks in outermost right lane

TR = (1.567 - 0.0826 * Ln (one-way ADT) - 0.123658 * LV)

where

LV = 0 if the number of lanes in one direction is 1 or 2

LV = 1 if the number of lanes in one direction is 3 or more

Statistics: R-squared = 0.52

Std Dev. = 13.0

n = 129 cases from six states

2. Proportion of all one-directional trucks in lane adjacent to (to the left of) outermost lane:

TL = (0.520 +0.0772 * Ln (one-way ADT) + 0.0564 * LV)

where

LV = 0 if the number of lanes in one direction is 1 or 2

LV = 1 if the number of lanes in one direction is 3 or more

Statistics: R-squared = 0.47

Std. Dev. = 11

n = 129 cases from six states

If there are only two lanes in one direction, TL is calculated as 1.00 - TR. Also if there are three or more lanes in one direction, the proportion of trucks in the inner lane(s) is calculated as 1.0 - TR - TL. This proportion applies to all lanes inside of the outermost two lanes regardless of the number.

2.4.3. PCA Distribution Factors

The Portland Cement Association in its guide for "Thickness design for Concrete Highway and Street pavements" has developed a chart representing the percent of trucks in the right lane of four lane and six lane divided highways based on the COPES equations. Figure 2.2 shows the plots of proportion of right lane trucks with Average Daily Traffic (ADT) flows (Portland Cement Association, 1984).

2.4.4. Other Lane Distribution Factors

Other highway departments in North America developed distribution factors for the design of pavements. In Texas, 100 percent of truck traffic is assumed in the design lane for design purposes (Texas Highway Department, 1984). But the use of 100 percent truck traffic allocation to the design lane is seen to significantly overestimate the actual truck traffic in the design lane (Cunagin, 1987).

The research report by the Texas Transportation Institute (TTI), which investigated the lane distribution factors used for design of pavements for Texas conditions, finds the COPES equations quite conservative, yielding truck distribution factor values which exceeded those observed in Texas. It is observed in the same report that even with the fairly wide AASHTO lane distribution factor ranges, 66% of the locations observed in the Texas studies had design lane percent values less than the suggested AASHTO minimum value (Cunagin, 1987).

The variations in truck lane distribution factors of the reviewed literatures suggest the non-uniformity of distribution factors from state to state and from province to province in Canada. Of more important influence to these differences are local and regional regulations regarding the lane use of trucks in the various provinces/states. In Alberta, heavy vehicles may use all the lanes of a multilane highway without restrictions. However, for reasons of safety and efficient operation, truck drivers remain mostly in the outside right lane than any other lane on a multilane highway. The foregoing differences among various departments, suggests a strong need for a comprehensive study to determine the truck lane use pattern in Alberta.

In determining the one-way lane distribution factors, the influence of pickups, panels and 2-axle, 4-tire trucks are excluded for both the AASHTO and the NCHRP studies. As reported by Cepas (1984) on the analysis of WIM scale data in Edmonton, over half of the urban truck traffic are of the two-axle, four-tire truck categories. These truck types generated 13.7 percent of the total ESALs. This finding is in keeping with the current publications of the National Truck Characteristics Report, which shows that two-axle, four tire trucks comprise between 40% to 65% of the total number of trucks with a national average of 49% but contribute less than 10% of the total ESAL generated by trucks (U.S. Department of Transportation, 1981).

2.5. Truck Weight Regulations

Truck Weight limits are recommended by highway agencies as a trade-off between the costs to build and maintain highways and the costs to transport goods by trucks. They also have implications for highway safety, traffic flow and highway finance. Weight limits are periodically revised to allow for improvements in highway design and vehicle performance.

Truck weight regulatory policies are developed based on a Federal Bridge Formula in the United States. The formula was derived from assumptions about the extent to which legal vehicles should be allowed to cause stresses that exceed the stresses assumed in bridge design (U.S. Secretary of Commerce, 1964; AASHTO 1983). The bridge formula is given as:

$$W = 500\ [LN/(N - 1) + 12N + 36]$$

where W is maximum weight in pounds carried on any group of two or more axles

L is distance in feet between extremes of any group of two or more consecutive axles, and

N is number of axles under consideration.

Specifically, this formula was designed to avoid overstressing HS-20 bridges by more than 5 percent and H-15 bridges by more than 30 percent. HS-20 is the minimum design load recommended by AASHTO for Interstate highways and is based on a 72,000-lb hypothetical vehicle with 8,000-lb axle and two 32,000-lb axles. An H-15 bridge is designed for a much lighter load (a hypothetical 30,000-lb vehicle with a 6,000-lb axle and a 24,000-lb axle).

2.5.1. Canadian (RTAC) Recommendations

In February 1988 the Canadian Council of Ministers of Transportation and Highway Safety under the Roads and Transportation Association of Canada (RTAC) recommended a common set of truck weight and dimension limits on highway pavement in Canada (RTAC, 1988). An important feature of the Canadian weight recommendations is the absence of an explicit bridge formula.

These limits were aimed at improving highway safety, protecting highway pavements against the destructive action of different axle configurations on pavements, and ensuring uniform inter-provincial trucking regulations. The recommendations suggested the use of four heavy truck configuration types whose axle arrangements ensure maximum freight loads with corresponding minimal destructive strains on pavements. The recommendations were adopted from results of studies undertaken on the impact of truck axle group and configuration spacing on pavement damage which revealed the need for an optimal axle group spacing to reduce pavement damage (Canroad Transportation Research Corporation, 1986; RTAC, 1987, Nix et al. 1987).

The recommendations agreed to on February 12, 1988 by RTAC sought to make uniform the dimensions of trailers, the limits of axle loads and gross vehicle weights (GVW) within the provinces. Other regulated aspects of trucks which were touched upon included the maximum spread of axles, inter-axle spacings, drawbar lengths, overhangs, etc. The summary in Table 2.4 and Figures 2.3 - 2.6 show an overview of the RTAC maximum allowable weight limits on front steering, single carrying, tandem and tridem axles. These values show changes in previous standards established and is reported to be justified in terms of net accrued benefits; that is in terms of trucking productivity benefits less increased road and bridge costs (Fredericks, 1989; Neal A.I. et al., 1989; Nix 1988).

For the sake of uniformity in weights and inter-provincial trucking efficiency, RTAC also reviewed the gross combination weights of trucks and defined four broad truck categories. Table 2.5 shows gross weight limits of RTAC recommended trucks. It is of interest to note that Alberta, British Columbia and Saskatchewan adopted a prior recommendation of the RTAC council of Ministers of Transportation and highway safety which allowed for a maximum of 25.0 meters overall vehicle length and 16.2 semi-trailer lengths as opposed to the later RTAC standards of 23.0 meters and 14.65 meters respectively (RTAC, 1988).

The recommendations resulted in a general increase of gross truck weights. The study by Nix reported an average increase of 10 tonnes on gross vehicle weight over the pre-RTAC weight limits across Canada (Nix, 1988).

2.5.2. Pre-RTAC Weight Limits

Before the RTAC regulations in 1988, provincial jurisdictions in Canada set axle load limits arbitrarily with little reference to the economic trucking of goods between provinces. Each province established its axle load limits based on the need to maintain a reasonable level of serviceability on its road network and the available funds for annual rehabilitation and maintenance programs. This resulted in inconsistent axle load limits across jurisdictional boundaries. The 1986 study conducted by Nix et al. on vehicle weight and dimensions regulations across the provinces highlighted the variation which existed before the RTAC regulations (Nix, 1987). An overview of the then existing limits on truck weight and dimension is given in Table 2.3.

The liberal regulations of some provinces led to the operation of different vehicle configurations that were not entirely desirable from the viewpoint of vehicle stability and handling. Other factors were the adverse effect of axle group loadings on pavement performance as the provinces differed in highway construction standards and the different tractor and trailer lengths which influenced the interaction between the truck and roadway geometrics.

These factors led to the series of studies which resulted in the RTAC recommending truck weight and dimension regulations for all the 10 provinces and 2 territories in 1988.

2.5.2.1. Limits in Alberta

Before the interprovincial regulations, weight limit enforcement in Alberta was based on the authorized load increases of 1974. The allowable legal maximum gross vehicle weight was increased from 72-kips to 80-kips in 1974. The "optimal" truck configuration according to Nix et al., was the 7-axle double with two trailers. "Optimal" means the largest truck allowed under the regulations. The 7-axle double truck type had a weigh out limit of 53.5 tonnes with trailers which measured up to 2 x 8.5 m but could be heavier or longer on some highways by special permit. This dimensions gave a maximum cube of 115 m^3 when larger combinations and special permit requirements are ignored.

2.5.3. RTAC Standard Trucks

To allow the trucking industry to acquire and operate trucks through all provincial jurisdictions, four standard configurations of tractor trailers were recommended by RTAC in 1988. The four categories of trucks are:

Category 1 : Tractor Semitrailer

Category 2 : A-Train double

Category 3 : B-Train double

Category 4 : C-Train double

2.5.3.1. Tractor Semitrailer

The research program sponsored by RTAC demonstrated that the tractor semitrailer truck type is the most inherently stable vehicle configuration of the four types studied. Before the proposed regulations, it has served as the predominant vehicle type used in interprovincial carriage because of its high productivity and flexibility. The elements of the configuration which were proposed for regulatory control and the proposed weight limits are summarized in Table 2.4, 2.5 and Figure 2.3. The proposed regulatory principles and limits were intended to encourage the continued use of this configuration, within the bounds of acceptable stability performance and infrastructure impacts.

2.5.3.2. A-Train Double Configurations

Figure 2.4 illustrates the A-train double configuration and their recommended dimensions and weight limits. The RTAC study showed this truck configuration to have potentially serious performance limitations, particularly with respect to the "Dynamic Load Transfer Ratio" and the "Transient High Speed Offtracking" compared to the other types.

2.5.3.3. B-Train Double Configurations

The B-Train double configuration has been shown to be the most stable of the recommended double trailer configurations. It has a capacity to accommodate further increases in both size and allowable weights without unduly compromising its desirable performance (RTAC, 1987). Figure 2.5 and table 2.5 show elements of this truck configuration and the weight limits proposed.

2.5.3.4. C-Train Double Configurations

The C-train double differs from the A-Train by its double drawbar connections between trailers. It also demonstrates superior stability performance to the A-Train and overcomes some of the operational difficulties of the B-Train. Elements of proposed configuration for this truck type is shown in Figure 2.6.

2.6. Weigh Scales

Information on truck volumes and the loading nature of trucks on the highway are required for accurate assessment of the number of repetitive destructive loading that a designed pavement thickness can withstand.

Volume and weight data can be obtained by means of static weigh scales or weigh-in-motion scales. As their names imply, static weigh scales require that vehicles are weighed while at rest but weigh in motion scales can gather information on trucks while moving at highway speeds.

2.6.1. Static Weigh Scales

Axle load data on the highway pavement are evaluated by sampling heavy trucks using Static weigh scales. Weighing trucks by static means requires the measuring of individual truck axles or axle group weights with portable weighing machines while the trucks are motionless. The set up of these scales requires the interfering of the flow of truck traffic and delay to truck operations since trucks are stopped and weighed. Static weigh scales also provide a limited amount of axle-load information because during the time that a truck is being weighed, other trucks would have to bypass the scale or queue up on the highway shoulder to wait their turn of being weighed. The development of Weigh-in-Motion (WIM) scales has provided the necessary technology for obtaining continuous axle load data without interfering with the traffic flow, thus eliminating the shortcomings of static weigh scales.

2.6.2. Weigh-in-Motion Scales

By definition, and by common usage, the term weight means that only gravitational force is acting on an object at rest. In-motion weighing of a highway vehicle attempts to approximate the gross weight of the vehicle or the portion of the weight carried by a wheel, an axle, or a group of axles on the vehicle by measuring instantaneously, or during a short period of time, the vertical component of dynamic (continually changing) force that is applied to a smooth, level road surface by the tires of the moving vehicle. The weigh-in-motion scale include a microprocessor-based scale system consisting of vehicle detectors and weight sensors embedded in the roadway width, with an electronics package located in a nearby interface box and a computer located in a static scale house.

WIM scales record axle load, vehicle speed and time of day at usual highway operation speeds. By interfacing the scale with a processing computer, the recorded loads of individual truck axles or axle assemblies are condensed and the equivalent single-axle load (ESAL) factors including traffic volumes of each vehicle class are compiled.

The equivalent single-axle load (ESAL) factors for the vehicle types are converted using the equivalency expressions incorporated in the computer system (Lowe and Bergan, 1983).

When weigh-in-motion scales are set up across all lanes of a multilane highway, vehicles are automatically classified and weighed in the individual lanes as they pass over the scale. The classification relies on the number of axles and axle configuration on each vehicle.

WIM scale installations reduce delay and unsafe queues on highway shoulders caused by permanent static weigh stations. As reported by Bergan et al., 1981, dynamic truck weights at WIM scales are recorded within $\pm 5\%$ of static weigh measurements at reasonable highway speeds.

2.6.3. Data Tables from WIM Scale

When vehicles passing over the WIM scale trigger the embedded traffic loops in the right order, the following information on each vehicle is condensed and recorded:

- the number of vehicles and 18-kips ESAL by day of week
- the average axle weights (in tonnes) by vehicle types
- Weight distribution (in tonnes) and average 18-kips ESAL by vehicle type.
- Car and single unit truck volumes by hour and day of week
- 5 axle semitrailers and other truck volumes by hour and day of week
- Numbers of truck axles by weight (tonnes)
- Traffic volumes by speed range
- Average axle spacing (meters) by vehicle type

Vehicles wandering from a lane, travelling in excess of 192 kph, or failing to trigger one of the traffic loops are recorded as "missed vehicles".

The date, time and duration of power failures are registered which allow for adjustments reflecting the missing periods of data acquisition to be made. Appendix A shows a typical weekly printout from the Leduc WIM scale site for two weeks in 1989.

2.7. Vehicle Classification

Vehicles in a traffic stream have varying characteristics which include their dimensions, visibility, maneuverability, acceleration, deceleration, braking, hill climbing, steering and cornering characteristics. These characteristics in one way or the other affect the operations and safety of the road network. Other characteristics of heavy vehicles such as the tire type, tire pressure, tire contact, tire configuration, axle configuration and axle static loads affects the performance of the pavement structure.

The classification of trucks is based mainly on tire and axle configuration, number of axles and the type and number of trailer units pulled by the tractor.

2.7.1. Classification at WIM scale Site

Vehicle classifications at the Leduc WIM site are defined on the basis of the weight of the second axle and the number of axles on each vehicle. The criteria for classifying vehicles is shown in Table 2.2. The system classifies vehicles into 19 classes based on the number of axles, axle configuration and the body type of each vehicle. Single unit and semi-trailer combination trucks which have greater deterioration effect on pavement structures are classified as of types 3 to 19. The analysis of truck traffic parameters in the research is based on vehicle categories falling within types 3 to 19 group.

The proposed RTAC truck configurations relates closely to heavy truck categories, described as types 9 through 19 at the Leduc WIM scale site in Alberta.

2.8. Load Assessment in Design Methods

All design procedures do not use the accumulated ESALs expected during the design life of a highway as their load input data. Procedures such as those of the Portland Cement Association (PCA) for portland cement rigid pavements design use as the traffic load input the expected axle load distribution of trucks using the highway. The Asphalt Institute (AI), the AASHTO design method, the RTAC pavement design method, CBR method of pavement design etc. use the ESAL concept for design. The damage relationship of loads on the pavement using these design methods indicate the power function of load on the effect on pavement wear.

Since trucks contribute the major proportion of total ESAL on highway segments, it is of importance to assess the proportionate magnitude of ESAL using each lane of a multilane highway for pavement design purposes.

In sum, extensive trucking activity and higher loading due to weight changes results in increased wear of existing pavements and bridge structures. There is also an associated increased maintenance costs and increased costs of new construction due to higher design standards required for increased pavement loadings.

2.9. Design Applications

Both flexible and rigid pavement design methods require the proportion of heavy vehicles using the design lane as input. For most highway pavement design applications the design lane is taken as the outside curb lane. Some agencies assign 100 percent of the one directional traffic including truck traffic volume to the design lane whereas other agencies have developed lane distribution factors for multilane facilities.

2.10. Operation Impacts

Lane choice of various classes of vehicles on a multi-lane highway facility vary considerably. The distribution depends on drivers' behavior in a region and regulations regarding lane use by heavy vehicles as well as the level of congestion of a lane and the condition of the roadway. Heavy vehicle categories in a lane have a direct impact on the traffic density on the travelled highway section. Trucks have low cruising speeds and their ability to climb steep grades are much lower than passenger cars. In the absence of climbing lanes or exclusive truck lanes for slow moving trucks the quality of traffic flow (level of service) is affected in the lanes used by the trucks. The effect of each truck on the traffic stream is measured in terms of passenger car equivalents. (HCM, 1985)

In situations where trucks are restricted from using the far left lanes or the median lanes on multilane highways, except for passing and/or overtaking, the number and proportion of trucks on the shoulder lane could exceed allowable limits. The shoulder lanes may be blocked while traffic in the left lanes may experience free flowing conditions, thus affecting the quality of service of the outside lane and the highway system in general.

2.10.1. Operations At Intersections

Large truck configurations have a substantial effect on traffic operations at intersections. Double trailer truck types are known to require additional time to complete right and left turning maneuvers (TRB SR 211, 1986). There is also an increased rate of encroachment over pavement edgelines and adjacent lanes for long trucks compared to other truck types because of offtracking or lateral displacement of the rear portion of the trailer (TRB 1986; DeCabooter et al, 1989). On narrow roads, this encroachment results in changes in the operations of oncoming vehicles.

Design elements of at-grade intersections such as sight distance, channelization, capacity and turning radius considered in intersection design, is essentially governed by traffic volume and vehicle characteristics. Selecting a design vehicle for intersection design is based on the anticipated frequency of larger truck units using the intersection. Vehicle type composition and the selection of the largest vehicle to be accommodated is sometimes assumed. The significant impact of vehicle type on traffic operations and the design of intersections is important for establishing appropriate design parameters (AASHTO, 1984).

2.10.2. Left-Turning Truck Lane Choice

Several research projects have been conducted to study traffic characteristics at at-grade intersections. Most of this research has been limited to the consideration of intersection flow patterns under different roadway and traffic conditions, vehicular delay and speed-change performance, time intervals accepted by drivers when crossing another traffic stream, and vehicular turning movements (TRB, 1985). However, truck lane choice and lane changes on turning has received little attention in these studies. Solberg and Oppenlander (1965) have provided data on the gap and lag acceptance for minor street vehicles entering or crossing main street traffic streams from stopped position. Wagner (1965), in dealing with gap and lag acceptance, also investigated the effects of certain factors on driver decisions. These factors included vehicle type, pressure of traffic demand, direction of movements through the intersection, sequence of gap formation, and conditions on the opposing side-street approach. He found that the traffic factors which significantly influenced driver decisions were the pressure of traffic demand, direction of traffic movement during periods of heavy demand and sequence of gap formation during periods of heavy demand. Noblitt (1959) dealt with gaps required by left-turning truck combinations and found that trucks required 1.4 to 1.8 times as large as the required gaps for cars in turning.

Table 2.1

Lane Distribution Factors

(AASHTO GUIDE, 1986)

Number of lanes in each direction	Percent of 18-kip ESAL traffic in design lane
1	100
2	80-100
3	60-80
4 or more	50-75

Table 2.3

Variations in PRE-RTAC Truck Weight and Dimension Limits across Provinces

(Nix 1987)

	Provincial limits
Height	4.2 - 4.5 m
Width	2.6 - 3.05 m
Length - semitrailers	13.5 m - no restriction
- tractor-semi	20.0 - 23.0 m
- doubles	21.0 - 24.4 m
AXLE LOADS	
- front, steering axles	5.5 - 9.1 t
- Single axles (dual tires)	8.1 - 10.0 t
- Tandem axles	16.0 - 20.0 t
- Tridem axles	27.0 - 30.0 t
GVWs - tractor-semi	37.5 - 63.5 t
- doubles	50.0 - 63.5 t

TABLE 2.2

Classification of Vehicles For Weigh-in-motion Scales
(Alberta Transportation)

CLASS	DESCRIPTION	AXLE SPACINGS	AXLE CONFIGURATION	DOMINANT VEHICLE(S)
1 	2 Axle vehicles 2nd axle < 2000		1:1	Passenger Cars
2 	3 or more axles 2nd axle< 2000kg			Psgr Cars + trailer
3 	2 axle single units		1:1	2S0
4 	3 axle single units	1-2 > 2.0 m 2-3 < 2.0 m	1:2	3S0
5 	3 axle single and trailer	1-2 > 2.0 m	1:1:1	2S0-1 2S1
6	3 axle undefined			
7 	4 axle single & trailer: semi	1-2 > 2.0 m 2-3 > 2.0 m 3-4 < 2.0 m	1:1:2	2S0-2 2S2
8 	4 axle undefined			3S1
9 	5 axle single & trailer; semi	1-2 > 2.0 m 2-3 < 2.0 m	1:2:2	3S2

		3-4 > 2.0 m 4-5 < 2.0 m		
10	5 axle semi and trailer 	1-2 > 2.0 m 2-3 > 2.0 m 3-4 > 2.0 m 4-5 > 2.0 m	1:1:1:1:1	2S1-2
11	5 axle undefined			
12	6 axl sgl & trlr 	1-2 > 2.0 m 2-3 < 2.0 m 3-4 > 2.0 m 4-5 > 2.0 m 5-6 < 2.0 m	1:2:1:2	3S0-3
13	6 axle semi and trailer 	1-2 > 2.0 m 2-3 < 2.0 m 3-4 > 2.0 m 4-5 > 2.0 m 5-6 > 2.0 m	1:2:1:1:1	3S1-2
14	7 axle single & trailer, semi and trailer 	1-2 > 2.0 m 2-3 < 2.0 m 3-4 > 2.0 m 4-5 < 2.0 m 5-6 > 2.0 m 6-7 < 2.0 m	1:2:2:2	3S0-4 3S2-2
15	7 axle semi and trailer 	1-2 > 2.0 m 2-3 < 2.0 m 3-4 > 2.0 m 4-5 < 2.0 m 5-6 > 2.0 m 6-7 > 2.0 m	1:2:2:1:1	3S2-2

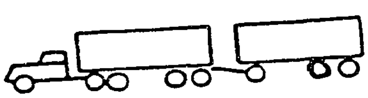
16 7 axle semi and 2 trailers

1-2 > 2.0 m 1:1:1:1:1:1:1 2S1-2-2
2-3 > 2.0 m
3-4 > 2.0 m
4-5 > 2.0 m
5-6 > 2.0 m
6-7 > 2.0 m

17 8 axle semi and 2 trailers

1-2 > 2.0 m 1:2:1:1:1:1:1 3S1-2-2
2-3 < 2.0 m
3-4 > 2.0 m
4-5 > 2.0 m
5-6 > 2.0 m
6-7 > 2.0 m
7-8 > 2.0 m

18 8 axle semi and 1 trailer



1-2 > 2.0 m 1: 2: 2: 1: 2 3S2-3
2-3 < 2.0 m
3-4 > 2.0 m
4-5 < 2.0 m
5-6 > 2.0 m
6-7 > 2.0 m
7-8 < 2.0 m

19 All 6; 7; 8 undefined axle vehicles together with vehicles having 9 or more axles

Table 2.4

1988 RTAC Recommended Maximum Weights on Axles (RTAC 1988)

AXLE TYPE		MAXIMUM WEIGHT ALLOWED (tonnes)	(kips)
Steering Axle		5.5	13.2
Single axle (Dual tires)		9.1	21.9
Tandem axles		17.0	40.8
	Variable with spread		
	2.4 m - 3.0 m	21.0	50.5
Tridem axles	3.0 m - 3.6 m	23.0	55.3
	3.6 m - 3.7 m	24.0	57.7

Table 2.5

RTAC GROSS TRUCK WEIGHT LIMITS (RTAC 1988)

TRUCK TYPE	**MAX. ALLOWABLE GVW** (tonnes)	(kips)
Tractor Semi-trailer		
--5 axle trucks	39.5	94.9
--6 axle trucks	46.5	111.7
A-Train double	53.5	128.4
B-Train double	62.5	150.0
C-Train double	53.5	128.4

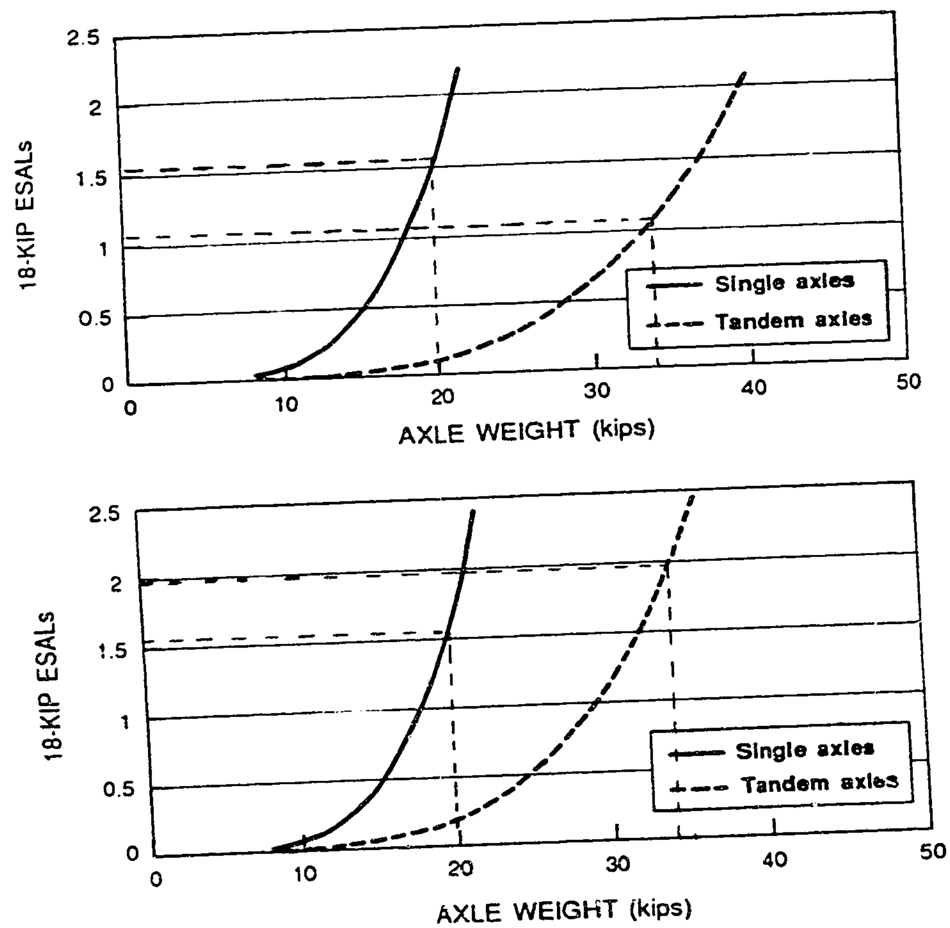


Figure 2.1 Effects of axle loads on pavement
Top: Flexible pavement
Bottom: Rigid pavements
(AASHTO 1986)
MODIFIED

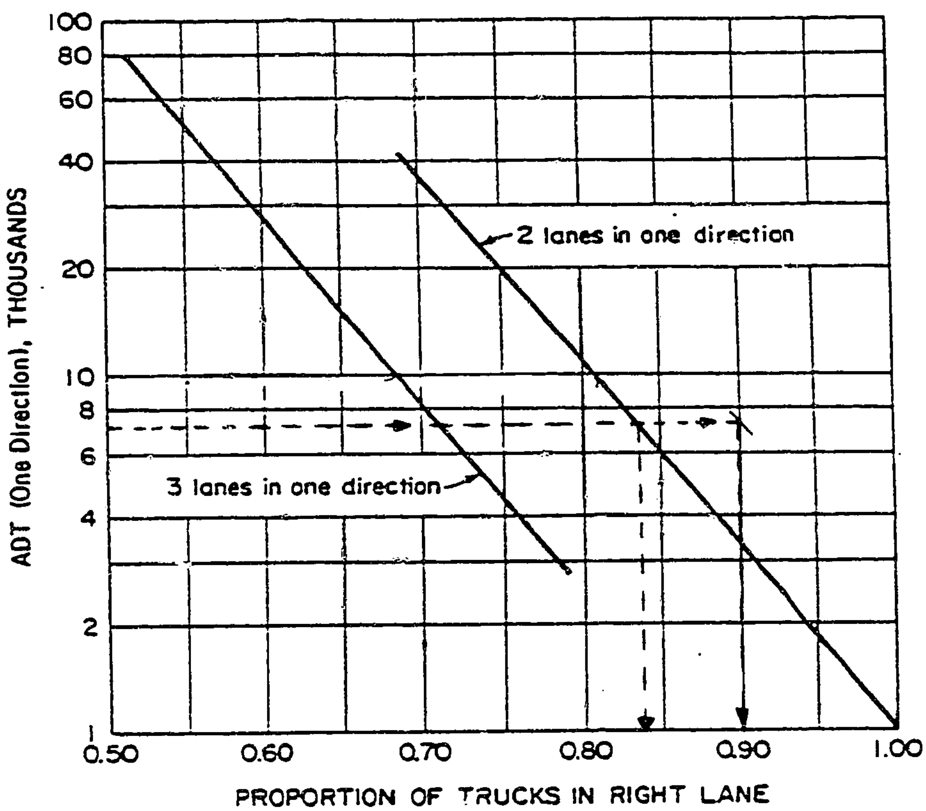
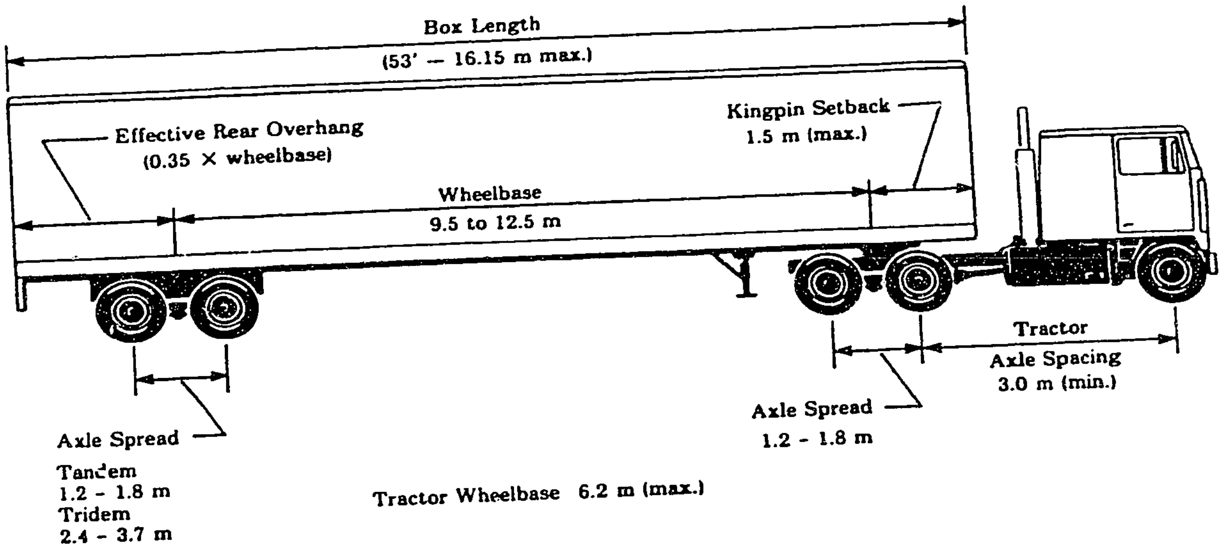


Figure 2.2 Proportion of trucks in the right lane of multilane divided highways (*PCA 1986* Modified)

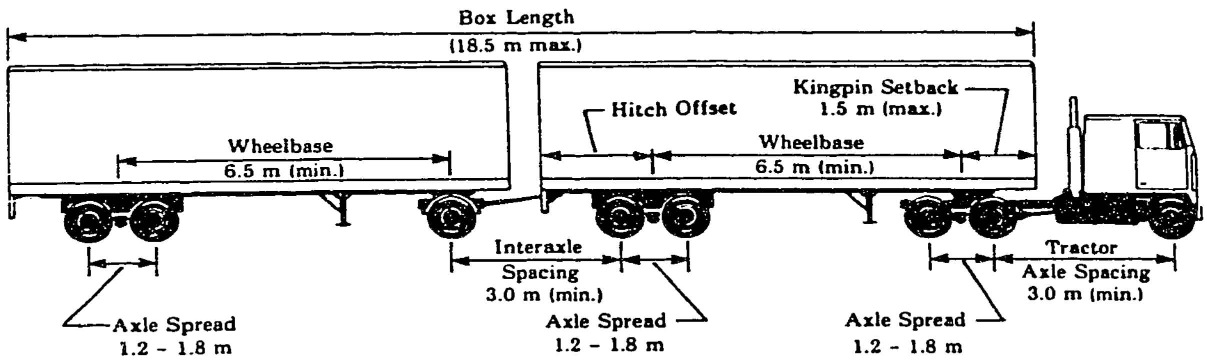


Tractor Semi-trailer

WEIGHTS

Axle Loads:		
Steering Axle	Yes	Max 5500 kg
Single Axle (dual tires)	Yes	Max 9100 kg
Tandem Axle	Yes	
Tandem Drive		Max 17000 kg
Tandem Trailer		Max 17000 kg
Tridem Axle	Yes	
Spread 2.4 m - less than 3.0 m		Max 21000 kg
Spread 3.0 m - less than 3.6 m		Max 23000 kg
Spread 3.6 m to 3.7 m		Max 24000 kg
Interaxle Spacings:		
Single - Tandem	Yes	Min 3 m
Tandem - Tandem	Yes	Min 5 m
Tandem - Tridem	Yes	Min 5.5 m
Gross Combination Weight	Yes	
Sum of Axle Loads (5 Axles)		Max 39500 kg
Sum of Axle Loads (6 Axles)		Max 46500 kg

Figure 2.3 Interprovincial limits for tractor-semitrailer Trucks (modified from *RTAC 1988*)

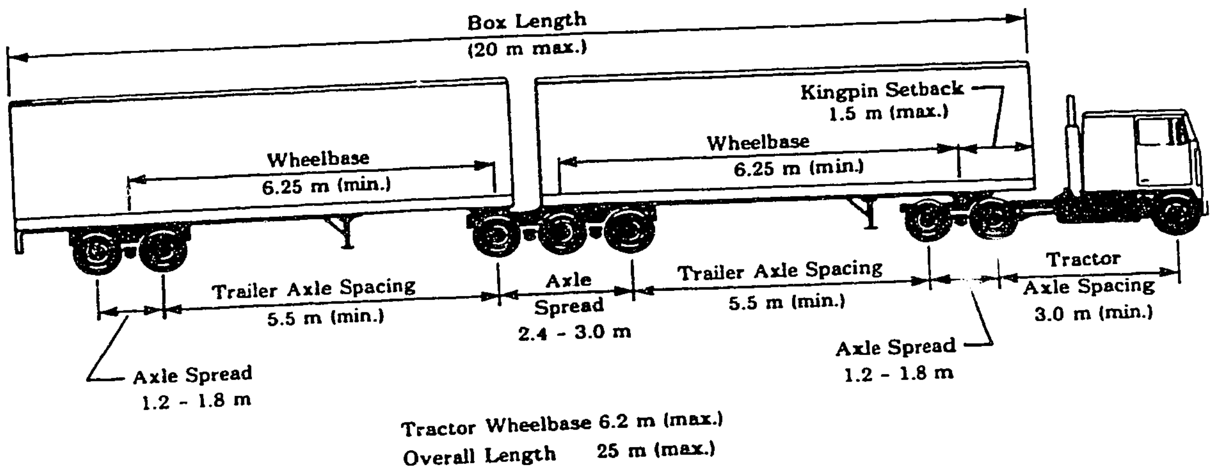


Hitch Offset	1.8 m (max.)	Drawbar Length	2.4 m (max.)
Tractor Wheelbase	6.2 m (max.)	Overall Length	25 m (max.)

A-Train

WEIGHTS		
Axle Loads:		
Steering Axle	Yes	Max 5500 kg
Single Axle	Yes	Max 9100 kg
Tandem Axle	Yes	Max 17000 kg
Sum of Axle Loads Second Trailer		Max 16000 kg
Interaxle Spacings:		
Single - Single	Yes	Min 3 m
Single - Tandem	Yes	Min 3 m
Tandem - Tandem	Yes	Min 5 m
Gross Combination Weight	Yes	Max 53500 kg

Figure 2.4 Interprovincial limits for A-train Double Trucks (modified from *RTAC 1988*)

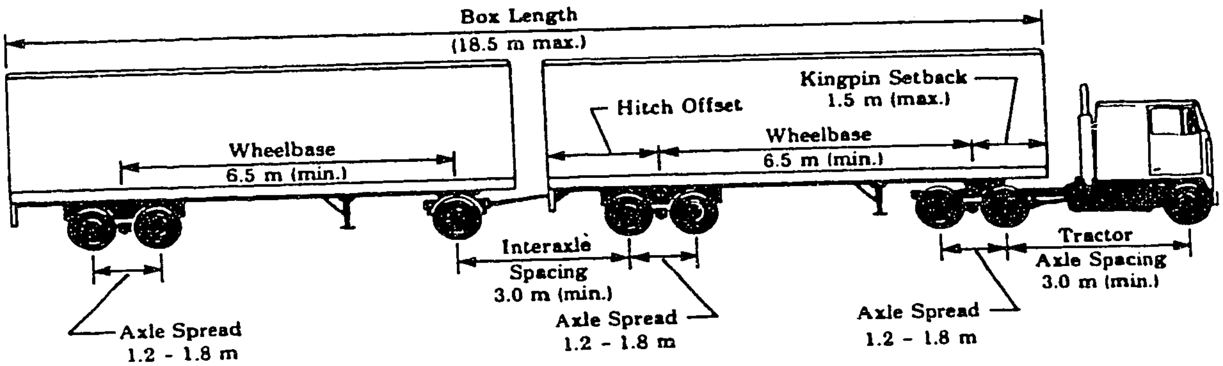


B-Train

WEIGHTS

Axle Loads:		
Steering Axle	Yes	Max 5500 kg
Single Axle (dual tires)	Yes	Max 9100 kg
Tandem Axle	Yes	Max 17000 kg
Tridem Axle	Yes	
Spread 2.4 m to less than 3.0 m		Max 21000 kg
Spread 3.0 m		Max 23000 kg
Interaxle Spacings:		
Single - Single	Yes	Min 3 m
Single - Tandem	Yes	Min 3 m
Tandem - Tandem	Yes	Min 5 m
Tandem - Tridem	Yes	Min 5.5 m
Gross Combination Weight	Yes	Max 62500 kg
Sum of Axle Loads (7 Axles)		Max 56500 kg
Sum of Axle Loads (8 Axles)		Max 62500 kg

Figure 2.5 Interprovincial limits for B-train Double Trucks (modified from *RTAC 1988*)



Hitch Offset 1.8 m (max.)

Tractor Wheelbase 6.2 m (max.)

Drawbar Length 2.4 m (max.)

Overall Length 25 m (max.)

C-Train

WEIGHTS		
Axle Loads:		
Steering Axle	Yes	Max 5500 kg
Single Axle	Yes	Max 9100 kg
Tandem Axle	Yes	Max 17000 kg
Sum of Axle Loads Second Trailer		Max 16000 kg *
Interaxle Spacings:		
Single - Single	Yes	Min 3 m
Single - Tandem	Yes	Min 3 m
Tandem - Tandem	Yes	Min 5 m
Gross Combination Weight	Yes	Max 53500 kg *

(*) Subject to review upon implementation of compliance standard for B Converter Dollies

Figure 2.6 Interprovincial Limits for C-train Double Trucks (modified from *RTAC 1988*)

CHAPTER 3

PRESENTATION AND VOLUME ANALYSIS OF WIM DATA

3.1. Introduction

The most common means of obtaining information on truck weights has been through the use of static weigh scales. These could be portable loadometers or permanent weight scale sites which are set up at strategic locations on the highway to assess sample weights of trucks. The shortcomings of this data collection approach are the lack of adequate axle load information on all vehicle types and the high labor and delay costs involved. With the development of the dynamic weigh-in-motion scale, continuous axle load data on vehicles can be obtained without interfering with the traffic flow on a highway section. One of such scales, set up on Highway 2 south of Leduc has provided traffic data since 1982.

Selected traffic data collected by Alberta Transportation and Utilities from the Leduc Weigh-In-Motion (WIM) scale site is presented in this chapter. The data are weekly compiled traffic volumes, equivalent single axle loads (ESALs) in lanes and ESAL factors by classed trucks in 1986 and 1989. Hourly, daily and seasonal variations in truck traffic parameters and the distribution of truck volumes in lanes including generated loads of axles are also analyzed. The analysis is intended to give an insight into the characterization of trucking activities in terms of equivalent single-axle loads (ESALs) on the particular rural multilane highway before and after changes in motor vehicle legislation in Alberta.

3.2. Data Source

Data presented in this chapter and for discussions in subsequent chapters were gathered from the Leduc WIM test site. Continuous data from this scale were obtained from the Alberta Transportation and Utilities between April and December 1986, and for all of 1989. Analysis of the weekly data showed approximately one-third of the total weeks had some data missing for various reasons.

3.2.1. The Leduc WIM Scale

The Leduc weigh-in-motion scale system was installed on the northbound lanes of section 2:30 of Highway 2 in 1982. This highway is a primary four-lane highway linking Edmonton and Calgary. The scale which was manufactured by the International Road Dynamics (IRD) is intended to provide data on vehicle classification, axle and gross vehicle weights and vehicle speeds. Traffic data from the scale is stored in computer files which are transmitted to departmental offices of Alberta Transportation and Utilities in Edmonton.

Figure 3.1 shows a schematic diagram of the WIM scale site in relation to the city of Edmonton. The scale system is said to offer high speed data collection and pre-screening capabilities to an accuracy comparable to static weighing scales. On the southbound approach lanes, a sorter scale has been established to pre-screen trucks reporting for mandatory weight checks and to measure truck weights as they enter a static weigh scale ramp.

3.2.2. Format of WIM Scale Data

Each week's compiled traffic data include a summary of the following statistics:

1. Number of vehicles and ESALs by day of week in lane 1 (outside lane) and lane 2 (inside Lane).
2. Average axle weights in tonnes by vehicle type.
3. Car and Single Unit Truck volumes by hour and day of Week.
4. Five-axle Semi's and other Truck Volumes by hour and day of week.
5. Traffic volumes by speed range.
6. Numbers of Truck axles by Weight (tonnes).
7. Weight Distribution in tonnes and Average ESAL by type.
8. Average axle spacing in meters by Vehicle Type.

A summary is also provided listing times and days when power interruptions occur.

All vehicles passing the scale are weighed with the exception of those failing to trigger the loops of the scale or those missing the scale entirely.

Appendix A shows a typical sample printout of two weeks collected data in May 1989.

3.3. Data Reduction

As part of this research, the data obtained was reduced to a suitable format for analysis by the use of Lotus 1-2-3 and Microsoft Excel computer spreadsheet programs. In all, 48 weeks of data were compiled for 1989 and 34 weeks for 1986. Data for the period between January and March of 1986 could not be obtained. The data values for this period were therefore obtained by extrapolation using the average annual weekly volumes calculated from the available data.

It was noted that about 27 weeks of all data collected during 1986 and 1989 had missing data for some days within the week. Possible explanation for such missing data could be malfunctioning of the scale due to power surges, failure of the scale's heating system in winter, and various technical reasons. Such data were corrected by eliminating the missing days and calculating the weekly values based on the available full days data.

Weekly statistics on the proportion of vehicles missed by the scale and periods of scale malfunctioning were used to make corrections in the data.

3.3.1. Proportion of Traffic Weighed

On average 75 percent of the one directional traffic are weighed by the scale. Vehicles are recorded as missed when the scale's weighing loops are triggered incorrectly, or an offscale detector is hit or when the scale is entirely missed.

A higher proportion of missed vehicles are recorded in the inside lane (31 percent of inside lane traffic) than the outside lane (24 percent of outside lane traffic).

3.3.2. Data Correction

The raw data were corrected for missed vehicles during short periods of scale malfunctioning by the use of cumulative distribution plots of the hourly volumes of trucks (Figure 3.2).

The use of Figure 3.2 for correcting raw data is illustrated by the following example. Truck volume count at the WIM site on a Monday in July was recorded as 506 trucks for the day. The summary statistics from the weekly printout showed that the scale was out of operation between 12:00 midnight and 9:00 A.M. Using the cumulative distribution chart, for a typical summer day, 20.2 percent of the daily trucks would be missed during this period. The corrected daily truck volume is therefore obtained as

Daily Truck Volume = 506/(1-0.202)
= 630

Such corrections and similar ones were applied to ESAL values and used in the analysis.

3.4. Seasonal Groupings

For the seasonal analysis of traffic volumes and loadings, the data were grouped into three main arbitrary periods. The seasonal groupings are summarized as follows:

Season	Description
November to February	Winter traffic
March to May	Spring traffic
June to October	Summer traffic

These limits do not coincide with conventional seasonal limits. They have been defined here on the basis of changes in traffic parameters as observed from the analyzed data.

3.5. Vehicle Classification

The vehicle classification system adopted at the WIM site distinguishes 19 vehicles on the basis of axle number and spacing, and a consideration of the weight of the second axle. Light Vehicles including light vehicles with trailers are classed as types 1 and 2. Two-axle six-tired to four-axle single unit trucks are classed between types 3 and 8. Five-axle semi's and trailer combination trucks are of types 9 to 19. The criteria for vehicle classification has been presented in Chapter 2, Table 2.2.

3.5.1. Truck Groups

Seventeen (17) truck types are classed by the scale. They have been grouped into two wide categories as light and heavy trucks for load analysis purposes. Trucks categorized as type 3 to 8 (2 axle single unit to four axle trucks) are classed light trucks and trucks with more than five axles (types 9 to 19) are referred to as heavy trucks.

3.6. Volume Analysis

The analysis of both 1986 and 1989 data are considered in parallel. Data from these two years provide a basis for assessing changes in truck loading after the RTAC truck weight limit recommendations and proposed standard trucks.

3.6.1. Average Daily Traffic

The one directional Average Annual Daily Traffic (AADT) based on 34 weeks data in 1986 was 6,500 vehicle per day (13,000 veh/day in both directions assuming an equal directional split).

In 1989, the AADT for the 48 week data collected was 14,600 veh/day in both northbound and southbound lanes.

3.6.2. Composition of Truck Traffic

The daily mix of trucks vary from 8.5 to 23 percent of daily traffic in the lanes. On average 11.8 percent of daily northbound lane traffic were trucks in 1989.

Trucks made up 10 percent of 1986 weighed traffic. Average daily truck traffic volumes were 1300 and 1720 trucks in 1986 and 1989 respectively. This translates into a 32 percent increase in ADTT within the analyzed periods.

In the analysis of general traffic volumes, vehicles which were not weighed or classified because they missed the scale were accounted for. Missed traffic are not classified by type therefore the proportion of trucks missed could not be determined and were not considered in truck analysis.

3.6.3. Truck Mix

The proportion of truck types in the traffic stream is shown in Figure 3.3. The predominant truck type is the five-axle semi and trailer truck which is classed at the scale site as type 9 trucks. The five-axle semi trucks make up about 40 percent of all weighed trucks. Heavy trucks represent 70 percent of all trucks weighed in 1989.

3.6.4. Hourly Peaking Patterns

Considering the hourly flow of traffic, over 85 percent of daily traffic flow occur between 6 a.m. and 8 p.m. Recorded mean peak hour traffic is 8.4 percent of the daily traffic. Peaking periods vary with the day of the week. Weekday peaking hours generally occur between 5 p.m and 6 p.m. Weekend traffic peaks much earlier in the afternoons than weekday traffic.

Flow patterns for truck traffic is more uniform during the day than it is for general vehicular traffic. On average, about 68 percent of truck volumes are recorded between 6 a.m and 8 p.m. Truck flows between 12:00 noon and 7 p.m accounts for over 40 percent of the daily total truck traffic. There is a peak hour flow for trucks which occurs around 12 noon with an hourly peaking factor of 6 percent.

3.6.5. Daily and Weekly Variation

Higher truck traffic activities occur during weekdays (from Monday to Friday) than weekends. Figure 3.4 and Figure 3.5 shows average number of trucks by the week day. Truck activities peak by mid-week.

Average daily truck volumes for each week is shown for both 1986 and 1989 in Figure 3.6. Truck volume data for weeks which showed abnormally low values due to system failures are excluded.

3.6.6. Seasonal Variation

Analysis of the weekly truck volumes (Figure 3.6) shows interesting information regarding truck volume changes within the year. The observed trend is that of lower daily truck volumes in the winter months which increases through spring to a peak in the summer months. The seasonal averages for truck and general traffic volumes within each season are tabulated in Table 3.1. Seasonal average ESALs and ESAL factors are also shown. Low traffic and truck volumes during winter period is attributed more to bad weather conditions and holidays than any other cause.

3.7. Conclusions

The Leduc Weigh-In-Motion scale set up on highway 2 and the data tables from the scale are described. Two years traffic volume data from this scale site have been discussed. About twenty-five percent of traffic is recorded as missed traffic by the scale. This occurs through wrong activation of the weight sensors. Major findings of this chapter are:

1. There was over 12 percent increase in general traffic volume between the analyzed periods, with 1986 as the base period.

2. Truck traffic composition: Weighed trucks represent approximately 11.8 percent of 1989 surveyed traffic. An increase of over 32 percent in truck volumes is noted if 1986 truck volume is used as the base year data. Five-axle trucks predominate the truck types weighed. These truck types together with six or more axle trucks (referred to as heavy vehicles) represent over 70 percent of trucks.

3. Truck Activities: Higher truck activities take place during the mid-week. The lowest truck volumes are

registered on Saturdays and Sundays. Within the year truck traffic volumes fluctuate from lower values during the winter and peaks in the summer months.

Table 3.1 (a)

Average Daily volumes By Season (1986)
(Northbound Lanes Only)

SEASON	AVG. DLY TRAFFIC	WEIGHED* DLY TRUCKS	AVG. DLY ESALs*	AVG ESAL FACTOR
Nov - Feb	5067	280	292	1.04
Mar - May	6038	452	495	1.10
June - Oct	7428	489	476	0.97
Annual	6700	450	453	1.00

Table 3.1 (b)

Average Daily volumes By Season (1989)
(Northbound lanes Only)

SEASON	AVG. DLY TRAFFIC	WEIGHED * DLY TRUCKS	AVG DAILY ESALs*	AVG ESAL FACTOR
Nov - Feb	5840	481	600	1.25
Mar - May	7311	605	927	1.53
June - Oct	8090	590	765	1.30
Annual	7330	570	770	1.35

* Unadjusted for non-classified traffic and days when scale was inoperative.

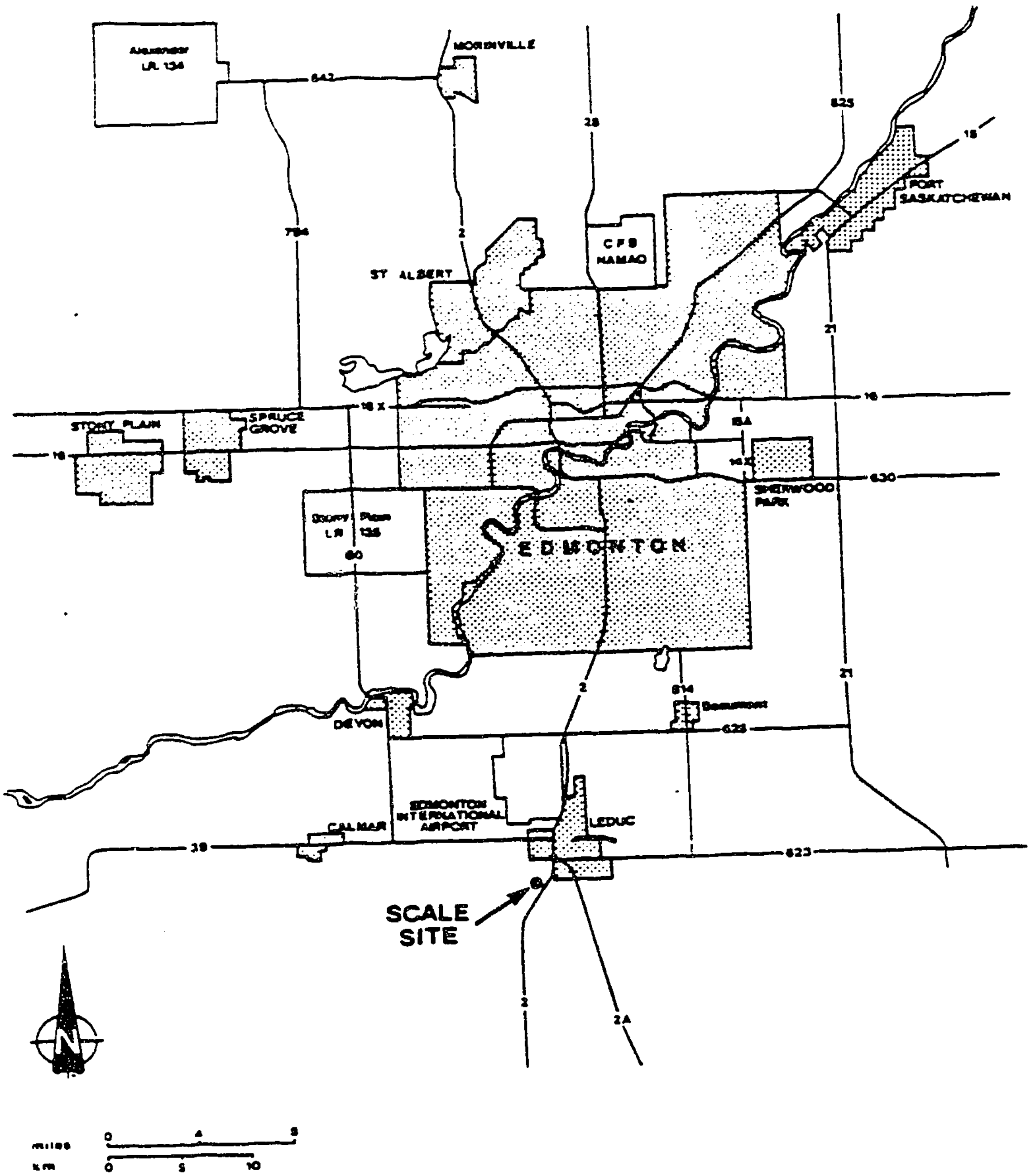


Figure 3.1 Weigh-in-Motion Scale Site at Leduc (*Alberta Transportion*)

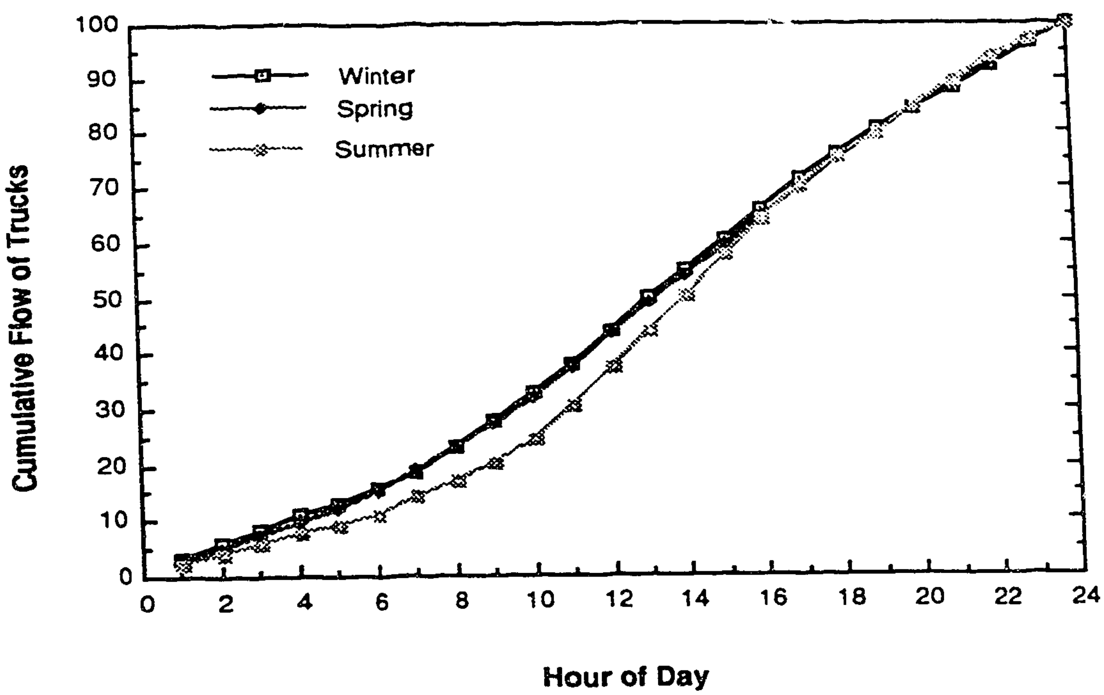


Figure 3.2 Cumulative Distribution of Hourly Truck Flows by Season.

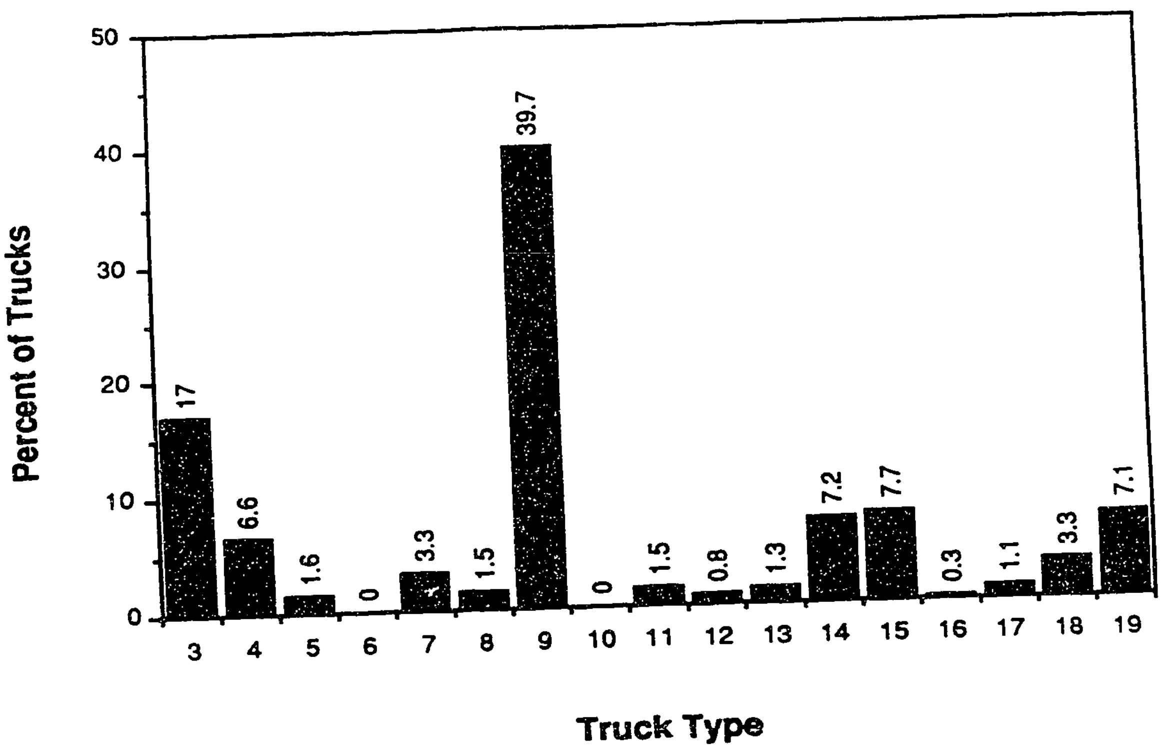


Figure 3.3 Truck Traffic Mix at WIM Scale Site

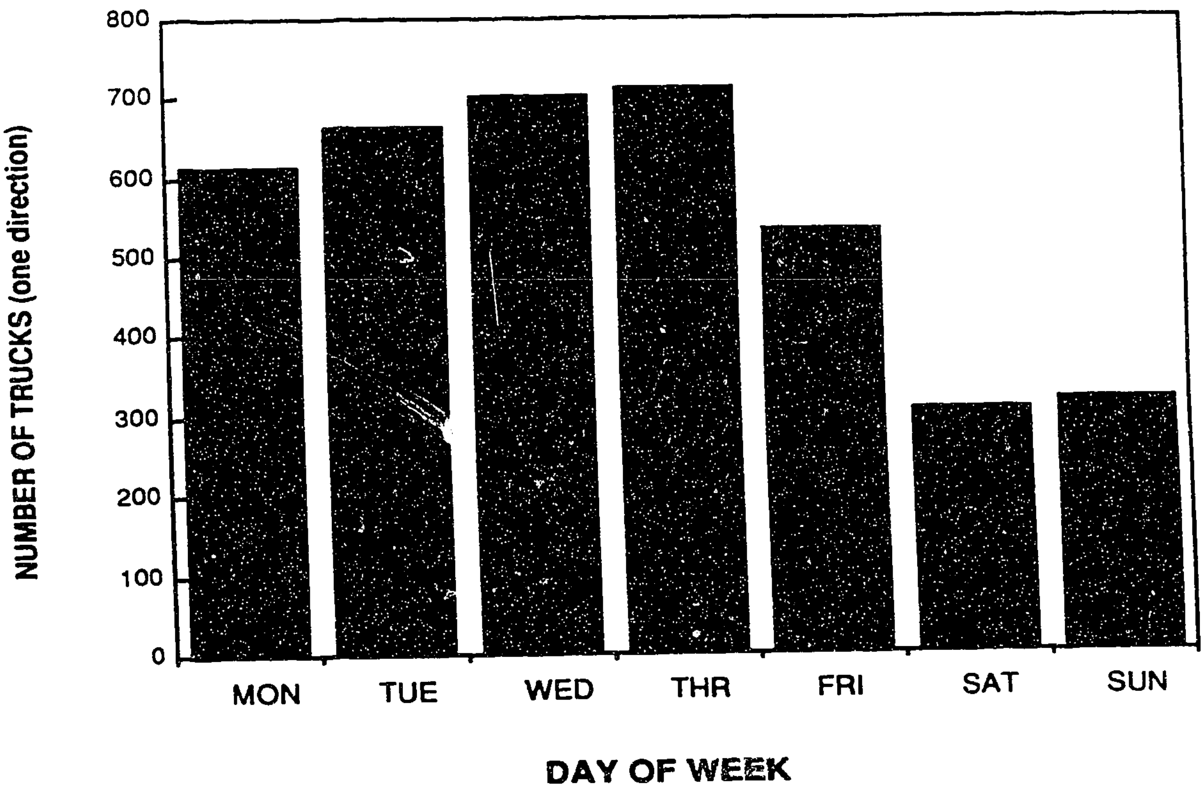


Figure 3.4 Daily Truck Volumes for a Typical Week

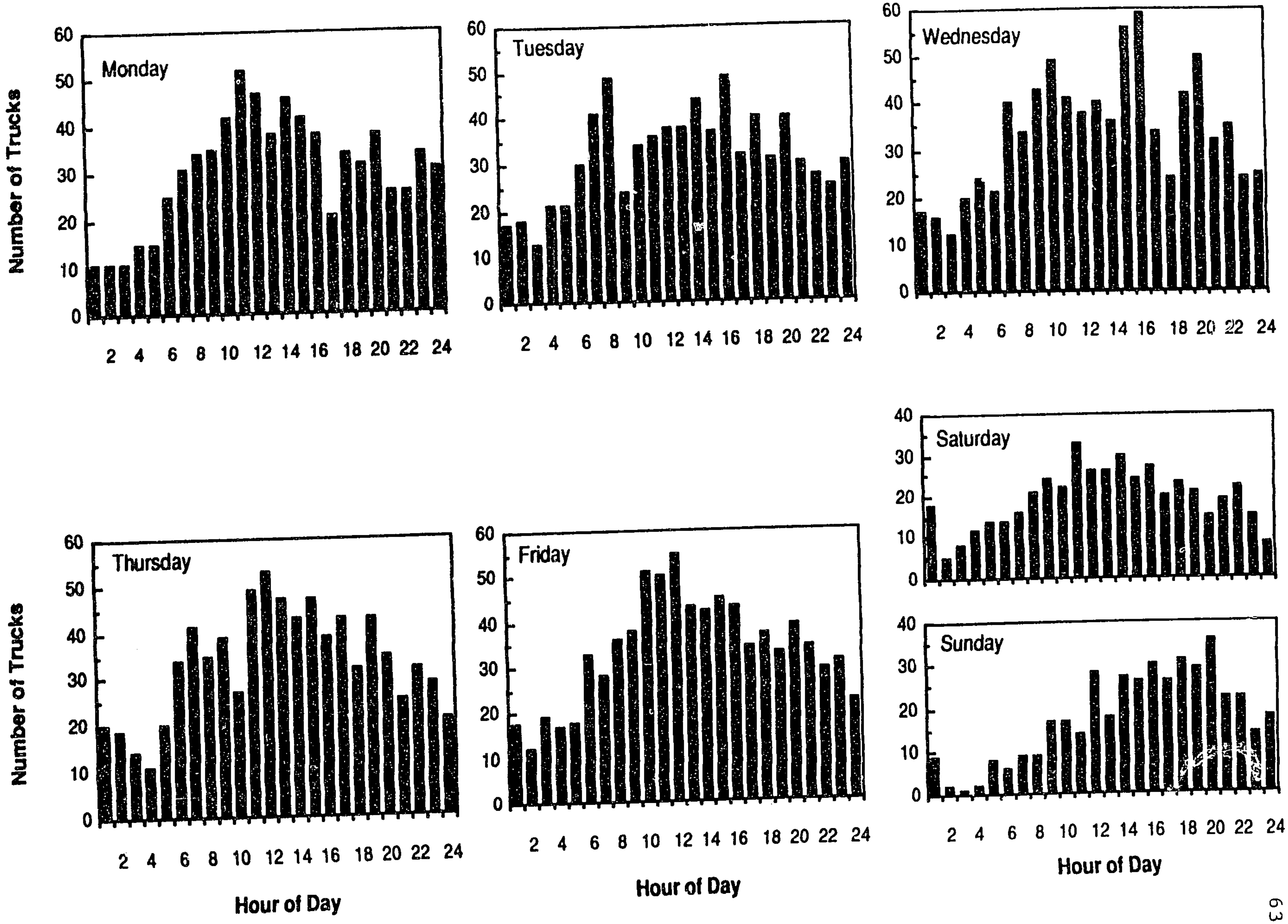


Figure 3.5 Hourly Flow of Trucks during weekdays

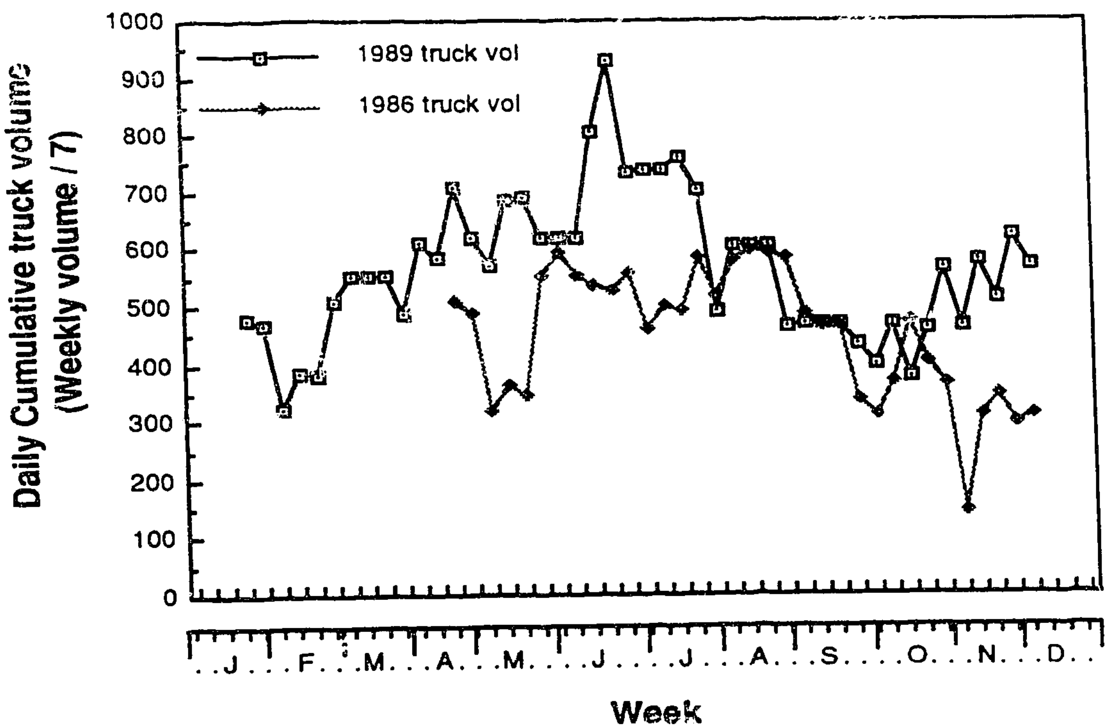


Figure 3.6 Daily truck volumes in Northbound lanes
(Missed trucks not included)

CHAPTER 4

GENERATED ESALs AND LOAD DISTRIBUTION

4.1. Introduction

In addition to information on the number of vehicles in each lane of a highway, the total number of axles and the magnitude of load imposed on the pavement by each axle must be known to predict accurately the accumulated number of wheel loads in a highway lane.

Most pavement design procedures now in general use are based on empirical considerations coupled with the evaluation of cumulative loading effects. These procedures define the design thickness of the pavement as a function of the number of applications of a standard 18-kip (80-kN) single axle load. To use this concept, the damaging effect of each axle load in a mixed traffic stream must be expressed in terms of the equivalent number of repetitions of 18-kip (80-kN) single axle load. The numerical factors that relate the number of passes of a 80-kN single axle load needed to cause pavement damage equivalent to that caused by one pass of a given axle load are called equivalent single-axle load (ESAL) factors or traffic equivalency factors.

Some other design procedures define the design thickness of the pavement as a function of the representative frequency distributions of axle weights for single, tandem and tridem axles on trucks using the highway.

Analyses performed on two years da[illegible]llected at the Leduc WIM scale site in the preceding chapter have enabled the assessment of truck traffic composition and volumes on Highway 2. In the present chapter, detailed axle weight and loading configuration assessment of trucks which are of potential use in pavement design and performance evaluation purposes are provided. Specifically, the resulting information and results are utilized to:

- determine changes in truck traffic loading which occurred after truck weight legislation in 1988,
- develop a relationship for estimating daily cumulative ESAL applications from truck volume data, and
- determine the variation in truck loading characteristics between the outside and inside lanes of the highway.

4.2. ESAL Repetitions

The concept of load equivalency is used to quantitatively assess the damaging effect of truck axle weights on pavements. It can be defined as that damage caused by the recorded load of individual axles or axle assemblies in terms of the number of repetitions of an 80-kN (or 8.2 tonnes or 18-kip) single axle load used as the standard load. A particular pavement is designed to support a particular number of repetitive cumulative ESALs within its design life. The total ESALs generated by heavy vehicles is obtained by summing the contributed ESALs of individual or group axles on a vehicle.

4.2.1. Daily ESALs

Trends in daily cumulative ESAL applications depend on truck number and magnitude of loading of each truck. Daily Cumulative ESALs generated during 1986 and 1989 are shown in Figure 4.1. The plots do not include ESALs generated by traffic missed by the weigh scales. There is a close relationship between daily ESAL fluctuations and daily truck volumes [discussed in chapter 3, Figure 3.6]. Recorded low truck volumes during the first week of February 1989 resulted in a corresponding low cumulative daily ESALs. The low volumes are explained by a snow storm during the period in the region. The harsh weather condition forced the closure of the highway to general traffic.

High daily ESALs are generated in the summer months. In 1989 the registered highest weekly ESAL was recorded in the second week of June. During this period the average daily cumulative ESALs of weighed vehicles was about 1400 ESALs.

The average annual daily ESAL applications, disregarding non-classified vehicles were 453 and 770 in 1986 and 1989 respectively. If it is assumed that the percent of missed trucks is proportional to the truck mix of weighed vehicles, the average annual daily ESALs would be 605 and 1025 ESALs respectively.

4.2.2. Seasonal Variation

As with truck volume fluctuations, higher daily ESAL values were generated during the March-May and June-October periods. The average daily ESALs by season were summarized with truck volumes in Table 3.1.

Winter periods (November-February) show characteristic low average ESAL values. Lower ESALs during this period is explained by low truck traffic operations and holidays. Seasonal truck loadings increase after the winter and is highest during the spring (March - May) period. This is reflected in the seasonal average ESALs per truck (ESAL factors) shown in Table 3.1.

4.2.3. ESALs by Truck Types

Heavy trucks generate over 89 percent of total daily ESALs on the highway. Five-axle truck categories alone contribute about half of the ESALs while seven-axle trucks contribute over 20 percent.

The proportion of daily cumulative ESALs contributed by the various truck types are shown in Figure 4.2. The daily ESAL contribution of type 6 trucks (3-axle undefined trucks) is negligible.

4.2.3.1. Heavy trucks

The average ESAL per pass (ESAL factors) for trucks of five or more axle configurations (heavy trucks) increased from 1986 to 1989 inclusive. This is shown in Table 4.1, where the percent increase in ESAL factors for each truck type are summarized. Since ESALs are exponential functions of axle weights, small differences in average weights or in the distribution between axles can cause large ESAL variations. A tabulation of the percent increase in truck axle weights is shown in Table 4.2.

Five-axle single and semi-trailer trucks were the predominant truck types at the site in both years. Five-axle trucks (types 9,10 and 11) represented 45 percent of all weighed trucks and contributed over half of all generated ESALs (54 percent). From 1986 to 1989 inclusive, the ESAL factor which reflects the average damaging units for five-axle semi-trailer trucks increased by over 26 percent.

Six-axle trucks (types 12 and 13) represent 2.1 percent of trucks. These truck types generate the highest ESALs per pass (4.29 ESALs/veh) but contributed about 4 percent of the total ESALs in 1989. Over 0.5 percent of these trucks generate ESAL factors of over 15.5. This is an indication that gross truck overloading could be of a significant number in this truck category.

Seven-axle truck volumes are the next predominant to the five-axle truck types. They represent 13 percent of all trucks and contribute 22.6 percent of total generated ESALs. The axles of these trucks are arranged in various forms. Trucks having configurations of a single front axle and three tandem axle groups generate the greatest ESAL factors on the highway. The average ESAL factor for these truck types are 2.51 ESALs/veh. At least one out of every 150 trucks classified in this category generated an ESAL factor over 12.5 for the analyzed data of 1989.

Gross vehicle weights as high as 80 tonnes (175-kips) resulting in as high as 25 damaging units per pass were recorded on eight axle and undefined-axle trucks (type 19). Average ESAL factor for the latter truck types was 2.14.

Eight-axle trucks (types 17 and 18 trucks) generated ESAL factors averaging 1.51 ESALs/veh.

4.2.3.2. Light trucks

The overall ESAL per pass contributed by light trucks decreased in 1989 with respect to 1986. Four-axle single and semi-trailer trucks (types 7 and 8) saw the greatest decline in average ESAL factors. This is reflected in the average gross weight and ESAL factor tabulations shown in Tables 4.1 and 4.2.

4.2.4. Weekly ESAL Factors

Plots of average ESAL factors by heavy trucks is shown in Figure 4.3. The plots show the weekly fluctuations in ESAL factors between January and August 1989 for selected heavy trucks. Truck types 9, 12, 14 and 18 (representing five, six, seven and eight-axle trucks) which form the dominant heavy vehicle categories on the highway are considered in these plots. Six-axle trucks (type 12) show much more variable but higher average ESAL factors. Five-axle semi-trailer trucks show a much more uniform trend in ESAL factors.

Across all truck types, an average ESAL factor of 1.05 and 1.4 resulted for 1986 and 1989 respectively. Heavy trucks represented 64 percent of 1986 weighed trucks with an average ESAL factor of 1.41. In 1989, heavy trucks produced on the average 1.9 ESALs per pass. This suggests the increased use of large combination trucks and the increased payloads of these trucks after the RTAC weight changes.

4.2.5. Daily ESAL and Truck Volume Relationship

Using loading data for 1989, regression analysis were carried out to obtain a relationship which can be used for estimating daily cumulative ESALs when the average daily truck volume (ADTT) is known. Such analysis were performed for vehicle loadings in both the inside and outside lanes. The best fit of regression line is fitted to the plotted data and a straight line relationship is found. The results and plots of this analysis are shown in Figures 4.4, 4.5 and 4.6.

The plots show the close relationship between the daily ESALs generated in the lanes and the truck traffic volumes within the individual lanes. A much better correlation (R^2 = 0.91) is observed between the two variables in the outside lane. A regression coefficient of 0.61 is analyzed for the inside lane. The derived relationships are given as follows:

For the Inside Lane:

$$Es = -4.71 + 2.04\ V$$

$$R^2 = 0.605$$

$$N = 112$$

Outside Lane

$$Es = -36.4 + 1.42\ V$$

$$R^2 = 0.905$$

$$N = 112$$

Both Northbound Lanes

$$Es = -38.7 + 1.47\ V$$

$$R^2 = 0.904$$

$$N = 112$$

where

Es = Daily cumulative ESALs generated by trucks.

V = Daily (24 hr) truck volumes.

Higher ESAL factors are generated in the inside lane as shown by a slope constant of 2.04 in the inside lane as against 1.42 in the outside lane.

4.2.6. Accumulated ESALs

The accumulated number of ESAL repetitions of all vehicles reflect the traffic associated pavement damage. Comparisons of eight months (between April and December) weekly accumulated ESALs for the two analyzed years at the scale site is shown in Figure 4.7. ESAL data for some weeks in 1986 were missing and have been interpolated using the average ESALs within each seasonal period.

Within the time interval considered, there was an increase in accumulated ESALs of over 80 percent. Increased ESALs in 1989 is explained by two main factors. These are:

1. A distinct increase in the volumes of heavy combination trucks (truck-trailer and combination units) in the traffic stream and
2. A pronounced increase in payloads of heavy truck categories. The shift in loading is partly influenced by a response to increased load allowances after the RTAC weight recommendations in 1988 and the economics in using the larger truck configurations. The recommendations encouraged gross weight increases in some heavy truck types and the introduction of the B-Train truck which had a much higher weight limit (63.5 tonnes). The changes therefore reflected the increase in the average gross weights of vehicles and the subsequent increase in ESALs.

4.2.7. ESAL Distribution

In Figure 4.8, plots of ESAL factors versus gross vehicle weight for light and heavy trucks are shown. These plots reflect the relative damage of the gross weight of each truck category. It is noted that ESAL factors increase sharply when the recommended weight limits are exceeded. For example, a 10 tonne increase in gross weight of a five-axle truck over its GVW limit of 39.5 tonnes results in the damage units increasing from 4.5 to 13 ESALs. Other truck types also show similar characteristics in loading and damaging values.

It is seen that a close relationship exists between damage units (ESAL factors) and truck gross weights which relates to the fourth power rule from the AASHO Road Test. Damage units as high as 38 ESALs were recorded for 7-axle trucks.

Figure 4.9(a) and 4.9(b) illustrate the distribution of truck numbers versus generated ESAL factor for [illegible] uck types. These plots are useful in assessing the prop[illegible] of trucks over the set weight limit for each truck type.

4.3. Average Gross Vehicle Weights

Gross vehicle weights (GVW) are obtained at the WIM site by the summation of all wheel, axle or axle group weights for each vehicle.

The average gross weights for vehicles are compared for both years in Table 4.2. A weighted gross average weight for all truck categories shows a weight increase of 1.8 tonnes soon after weight changes in 1988. This represents about 9 percent increase over pre-RTAC average gross vehicle weights. The overall gross average weight is calculated by weighting the gross weights of each truck category using the proportion of trucks within the category. The greatest gross weight increases were found to be within the truck-trailer and combination categories. The average weight and proportion of light truck categories such as the three-axle and four-axle trucks decreased after the changes.

4.4. Axle Weight Distribution

Five types of axle groups are defined on trucks. These are front steering axles, single axles, front tandem axles, tandem axles and tridem axles. The recommended allowable weights on these axle groups have been discussed in chapter 2.

With the exception of front tandem axles which showed a reduction in average weights, the average weights on other axle groups increased in 1989. The most significant increase was in the number and weights of tridem axle groups. The average weight on these axles increased by a factor of 0.9 between the analyzed periods. A summary of average axle weights for all axle types is shown in Table 4.3.

Plots of the distribution of single, tandem and tridem axle weights are illustrated in Figure 4.10(a-c). The percent of overloaded axles using the limits recommended by RTAC are shown on the plots.

In Table 4.4, the distributions of axle loads per 1000 trucks sampled are tabulated. At the scale site, gross vehicle and axle weights are measured in tonnes. For use with various pavement design procedures whose load distribution input are measured by the imperial or metric units, the distributions have been converted into kips, kN and tonnes.

Single axle loadings are grouped by 8.8 kN (1-kip) increments whilst tandem and tridem axles are grouped by 17.6 kN (2 kips) increments.

Adjustments are made to account for panels, pick-ups and 2-axle single unit trucks (type 3 trucks). These truck types represent about 18 percent of all weighed trucks.

A shift to the increasing use of tridem axle groups on trucks is evident from the analysis of the proportion of each axle group. Single, tandem and tridem axles represented 52.8, 47 and 0.2 percent respectively of all weighed axles in 1986. In 1989 the distribution was 52.1, 46.2 and 1.5 percent respectively.

4.5. Overloads on the Highway

A significant factor contributing to early pavement wear and the deterioration of road structures is the destructive effect of overloaded trucks.

The term overloaded, as used in this research, describes trucks with axle loads or gross vehicle weights exceeding the recommended RTAC limits as presented and discussed in chapter 2.

Permit overloads may result when special restricted permits are granted by road agencies, for the operation of trucks intended for moving heavy machinery or indivisible loads from factories to sites through the highway system.

The concept of load equivalency factors is extended in this research to estimate the damage from overloaded vehicles on pavements.

Although, permanent weigh scales (vehicle inspection stations, VIS) and mobile units are set-up at various stations on the provincial primary highway system to help control overloading, these stations could be bypassed through alternate routes. Bypassing weigh scales can defeat the weight enforcement effort implemented by enforcement agencies. In Alberta weight limit implementation is enforced by the Motor Transport Services Division of Alberta Transportation and Utilities for provincial highways.

Using Weigh-in-motion scales to monitor vehicle overloads may be considered more reliable than static weigh scales on highway pavement. This is mainly due to the fact that all trucks are weighed and truckers have no fear of being apprehended by enforcement agencies based on the WIM data.

An analysis of truck overloads is summarized in Tables 4.5 (a and b) using truck weight data for both 1986 and 1989.

4.5.1. Gross Truck Overloads

At least 3.4 percent of all trucks were overloaded in 1989. This proportion of trucks contributed over 17.5 percent of generated ESALs. Considering overloads within truck mix, 26 percent of type 12 trucks (6-axle semi) were overloaded.

Although only 4.4 percent of 5-axle semi trucks were overloaded, more than 50 percent of total overloaded ESALs were from this truck category. Overloaded trucks generated an average ESAL factor of 7.0 ESALs/veh.

4.5.2. Axle Overloads

With respect to the individual axle groups, Table 4.7 and Figure 4.10 summarizes the proportion of axles which are overloaded. Figure 4.10 (a and b) also show how each axle group is distributed with weight. The increased use of tridems in 1989 also resulted in a higher proportion of overloads (12.5 percent of all weighed tridems) within this axle category.

4.6. Lane Distribution

In addition to the number of trucks and the ESALs generated on the highway, the selected lane for travel is of major concern in the design of pavements and the operations of traffic on the highway.

As shown by Darter et al. (1985) and the Portland Cement Association, PCA, (1984), the greater part of truck traffic use the outside lane for travelling on multilane highways. As the lanes of the highway become congested from increased traffic, more trucks in the traffic stream will tend to shift into and use the inner lanes.

4.6.1. Vehicle Lane Use

With reference to the northbound traffic at the scale site, about 74 percent of all traffic volumes keep to the outside right lane (lane 1). This proportion is found to vary little over the period of traffic analyzed and with seasonal changes.

4.6.2. Proportion of Trucks and Loading in Lanes

The outside right lane accommodates on average 90 percent of total truck traffic volumes and about 85 percent of the one-directional accumulated ESALs. During the winter months, the proportion of trucks in the outside lane drops slightly to between 88-90 percent.

Comparing these lane distribution factors with those suggested by the PCA (1984), it is found that a greater proportion of trucks use the right lane on Highway 2 than recommended by the PCA. For a one directional ADT of 7,300, the PCA chart results in 82 percent of trucks in the right lane of the highway (see Figure 2.2).

The analyzed distribution factors is within those recommended by AASHTO (1984). The AASHTO guide suggests between 80-100 percent of 18-kip ESAL traffic in the outside design lane of a four lane multilane highway.

4.6.3. ESAL Factors in Lanes

Lane by lane analysis of accumulated ESALs show that more ESALs are generated in the outside lane (85 percent of ESALs) than the inside lane (15 percent). This distribution is a direct result of a higher truck proportion (90 percent average) in the outside lane. On the other hand, when the average ESALs per pass is considered for the individual lanes, trucks in the inside lane are found to generate higher ESALs per pass.

This conclusion is shown clearly in Figure 4.4 (a). In this plot, expressions relating the daily truck volumes to the daily cumulative ESALs in both lanes are shown. Trucks in the inside lane generate over 2.0 ESALs per pass while outside lane trucks generate about 1.4 ESALs per pass. This trend is found to be consistent for all surveyed truck types. A summary of generated ESAL factors within lanes for all truck types is shown in Table 4.8. Higher coefficient of variations (c.v.) for inside lane trucks show how variable truck loadings are in this lane.

4.7. Conclusions

Truck traffic data for two comparative years from a multilane WIM system in central Alberta has been outlined. Based on analysis of truck axle weight and generated ESALs, the overall changes in truck traffic loads occurring on Highway 2 between the two years, 1986 and 1989, have been determined. Relationships for estimating pavement loadings, based on daily truck volumes, have also been developed and the loading in both the inside and outside lanes of the multilane highway have been compared. Major findings of this chapter are:

1. Increases in average truck axle weights, changes in truck traffic composition and increases in truck volumes have together contributed to significant increases in total ESALs after the RTAC recommendations on vehicle weights and dimensions in 1988. There was a 1.8 tonnes increase in the weighted gross weight of trucks soon after the weight changes.

2. The trend in seasonal variation of weekly generated ESALs follows closely the cumulative number of trucks on the highway. High total ESALs and ESAL factors are generated in the spring and summer months but are at their lowest during the winter periods.

3. Most ESALs on the highway are generated by heavy truck categories. These truck types represent 64 percent of all trucks but generate 89 percent of the daily ESALs.

4. ESALs per pass increased within the analyzed period. The most significant increase were in semitrailer and combination truck units. ESAL factors for all truck types using the inside lane showed consistently higher values than those in the outside lane. On average, a factor of 2.04 was

determined for truck loading in the inside lane while a factor of 1.41 was established for the outside lane traffic.

5. There is a direct relationship between daily truck volumes and generated ESALs on the highway. A correlation coefficient of 0.905 was achieved for the outside lane and 0.605 for the inside lane.

6. Overloaded trucks represented 3.4 percent of all trucks and contributed about 18 percent of generated ESALs on the highway in 1989. With regards to axle groups, most overloads were on the tridem axle group.

Table 4.1

ESAL FACTORS FOR CLASSIFIED TRUCKS
1986/1989

Truck Type	*ESAL Factor (1986)*	*ESAL Factor (1989)*	*Percent Change*
3	0.18	0.21	16.6
4	0.78	1.05	34.6
5	0.30	0.29	-3.3
6	0.40	0.65	--
7	0.53	0.47	-11.3
8	0.80	0.62	-22.5
9	1.32	1.67	26.5
10	0.36	0.88	144.0
11	1.18	1.37	16.0
12	2.71	4.29	58.3
13	0.82	0.92	12.2
14	1.87	2.51	34.2
15	1.84	2.41	31.5
16	0.71	0.93	31.0
17	0.99	1.04	5.0
18	1.21	1.65	36.4
19	1.45	2.14	47.6

Table 4.2

Average Gross Truck Weights (tonnes)

	1986			1989			
Type	**Avg Weight**	**% Trks**	**Wghtd Av**	**Avg. Gross Wght**	**% Trks**	**Wgted Av**	**% Change**
3	5.3	19.6	103.9	5.6	21.4	119.8	5.7
4	13.6	8.2	111.5	14.2	6.8	96.6	4.4
5	7.9	2.3	18.2	8.1	2.2	17.8	2.5
7	12.8	4.2	53.8	11.6	4	46.4	-9.4
8	12.6	1.6	20.2	12.8	1.8	23.0	1.6
9	23.9	43	1027.7	25.2	37	932.4	5.4
10	15.9	.5	8.0	17.9	.12	2.15	12.6
11	19.9	1.1	21.9	20.9	1.1	23.0	5.0
12	38.3	.9	34.5	39.7	1.02	40.49	3.7
13	23.5	1.2	28.2	23.9	1.2	28.7	1.7
14	32.2	6.3	202.9	35.8	6.2	222.0	11.2
15	30.0	6.4	192.0	35.9	5.9	211.8	19.7
16	22.9	.3	6.9	27.3	0.02	0.55	19.2
17	30.3	1.1	33.3	31.4	.88	27.63	3.6
18	37.9	1.7	64.4	37.9	2.9	109.9	0.0
19	28.9	1.6	46.2	35.9	7.0	251.3	24.2
Total			1973.7			2153.63	

Average Gross Weight increase = 1.8 tonnes i.e. 9 percent

Table 4.3

AVERAGE WEIGHTS ON AXLES
(TONNES)

Axle type	1986	1989	Percent wgt incr
Front steering axles	3.3	3.6	9 %
Single axles	3.9	3.9	0 %
Front Tandem axles	11.2	9.3	-17.1 %
Tandem axles	10.0	10.2	2 %
Tridem axles	7.7	14.6	90 %

Table 4.4 (a)

AXLE LOAD DISTRIBUTION

Axle load (kips)	Axle load (kN)	Axles per 1000 trucks	Adjusted Axles per 1000 trucks
SINGLE AXLES			
30 - 32	133 - 142	0.16	0.20
28 - 30	125 - 133	0.29	0.36
26 - 28	116 - 125	0.44	0.54
24 - 26	107 - 116	0.96	1.19
22 - 24	97.9 - 107	2.72	3.36
20 - 22	89.0 - 97.9	7.06	8.72
18 - 20	80.0 - 89.0	14.45	17.84
16 - 18	71.2 - 80.0	32.06	39.58
14 - 16	62.3 - 71.2	52.89	65.30
12 - 14	53.3 - 62.3	80.81	99.77
TANDEM AXLES			
64 - 68	285 - 302	0.03	0.04
60 - 64	267 - 285	0.08	0.10
56 - 60	249 - 267	0.48	0.59
52 - 56	231 - 249	1.57	1.94
48 - 52	213 - 231	3.62	4.47
44 - 48	196 - 213	9.48	11.70
40 - 44	178 - 196	25.51	31.49
36 - 40	160 - 178	81.45	100.56
32 - 36	142 - 160	164.86	203.53
28 - 32	125 - 142	223.86	276.37

Table 4.4 (a) (cont.)

AXLE LOAD DISTRIBUTION

Axle load (kips)	Axle load (kN)	Axles per 1000 trucks	Adjusted Axles per 1000 trucks
TRIDEM AXLES			
64 - 68	285 - 302	0.05	0.06
60 - 64	267 - 285	0.13	0.16
56 - 60	249 - 267	0.66	0.81
52 - 56	231 - 249	2.11	2.60
48 - 52	213 - 231	3.49	4.31
44 - 48	196 - 213	6.11	7.54
40 - 44	178 - 196	5.34	6.59
36 - 40	160 - 178	3.09	3.81
32 - 36	142 - 160	2.27	2.80
28 - 32	125 - 142	1.71	2.11

Table 4.4 (b)

AXLE LOAD DISTRIBUTION

Axle load (tonnes)	Axles per 1000 trucks	Adjusted Axles per 1000 trucks
SINGLE AXLES		
14.0 - 15.0	0.08	0.10
13.0 - 14.0	0.23	0.28
12.0 - 13.0	0.44	0.54
11.0 - 12.0	0.94	1.16
10.0 - 11.0	2.90	3.58
9.0 - 10.0	7.91	9.77
8.0 - 9.0	17.67	21.81
7.0 - 8.0	41.04	50.67
6.0 - 7.0	67.49	83.32
5.0 - 6.0	122.85	151.67
4.0 - 5.0	354.94	438.20
TANDEM AXLES		
28.0 - 30.0	0.06	0.07
26.0 - 28.0	0.34	0.42
24.0 - 26.0	1.32	1.63
22.0 - 24.0	3.37	4.16
20.0 - 22.0	10.17	12.56
18.0 - 20.0	29.08	35.90
16.0 - 18.0	101.50	125.31
14.0 - 16.0	204.91	252.98
12.0 - 14.0	246.91	304.83
10.0 - 12.0	182.46	225.26
8.0 - 10.0	168.01	207.42

Table 4.4 (b)(cont.)

AXLE LOAD DISTRIBUTION

Axle load (tonnes)	Axles per 1000 trucks	Adjusted Axles per 1000 trucks
TRIDEM AXLES		
28.0 - 30.0	0.13	0.16
26.0 - 28.0	0.29	0.36
24.0 - 26.0	1.97	2.43
22.0 - 24.0	3.51	4.33
20.0 - 22.0	6.67	8.23
18.0 - 20.0	5.73	7.07
16.0 - 18.0	3.17	3.91
14.0 - 16.0	2.44	3.01
12.0 - 14.0	1.42	1.75
10.0 - 12.0	0.88	1.09
8.0 - 10.0	0.94	1.16

Table 4.5 (a)

Overload Information on Truck Traffic - 1986

Type	# of trucks	Average ESAL/Pass	Total ESALs	ESALs due to overlds (%)	% Trucks overload
3	69517 (19.6%)	0.18	12513.06	977.6 (7.8%)	0.30
4	29009 (8.2%)	0.78	22627.02	3705.3 (16.4%)	1.87
5	8198 (2.3%)	0.30	2459.40	81.0 (3.3%)	0.37
7	14872 (4.2%)	0.53	7882.16	533.3 (6.8%)	0.43
8	5540 (1.6%)	0.80	4432.00	620.5 (14%)	2.01
9	152533 (43%)	1.32	201343.56	32869.5 (16.3%)	3.03
10	1936 (0.5%)	0.36	696.96	31.8 (4.6%)	0.15
11	3834 (1.1%)	1.18	4524.12	828.99 (18.3%)	2.92
12	3265 (0.9%)	2.71	8848.15	3074.03 (34.7%)	12.96
13	4251 (1.2%)	0.82	3485.82	122.39 (3.51%)	0.45
14	22193 (6.3%)	1.87	41500.91	3403.34 (8.2%)	1.79
15	22795 (6.4%)	1.84	41942.80	2966.64 (7.1%)	1.19
16	1143 (0.3%)	0.71	811.53	--	--
17	3692 (1.1%)	0.99	3655.08	--	--
18	6052 (1.7%)	1.21	7322.92	24.05 (0.3%)	0.03
19	5847 (1.6%)	1.45	8478.15	419.36 (4.9%)	0.58

Total Weighed Trucks = 354,722

Total Generated ESALs from Trucks = 372,530.64

ESAL Factor for all Trucks = 1.05

ESALs generated by heavy trucks = 322,610.00 (86.6 %)

ESAL factor for heavy vehicles = 1.42

Overloads

ESALs from overloaded trucks = 49,957.8 (13.4%)

Percent trucks overloaded = 1.93 %

Table 4.5 (b)

Overload Information on Truck Traffic - 1989

Truck type	# of trucks	Average ESAL/Pass	Total ESALs	ESALs due to overlds (%)	# Trucks overlded (%)
3	30228 (21.4%)	0.20	6045.60	611.1 (10.1%)	131 (0.43)
4	9569 (6.8%)	1.05	10047.45	1260.3 (12.5%)	234 (2.4%)
5	3050 (2.2%)	0.29	884.50	40.9 (4.67%)	4 (0.13%)
6	20 (0.01%)	0.65	13.00	0.0	0
7	5661 (4%)	0.47	2660.67	248.9 (9.33%)	24 (0.42%)
8	2578 (1.8%)	0.62	1598.36	206.4 (12.9%)	34 (1.32%)
9	52560 (37%)	1.67	87775.20	15949.8 (18.2%)	2354 (4.4%)
10	164 (0.12%)	0.88	144.32	44.3 (30.54%)	4 (2.44%)
11	1625 (1.1%)	1.37	2226.25	285.4 (12.79%)	40 (2.46%)
12	1441 (1.02%)	4.29	6181.89	2805.4 (45.4%)	375 (26.0%)
13	1765 (1.2%)	0.92	1623.80	83.47 (5.15%)	10 (0.57%)
14	8803 (6.2%)	2.51	22095.53	3933.3 (17.84%)	447 (5.08%)
15	8390 (5.9%)	2.41	20219.90	1764.0 (8.7%)	172 (2.05%)
16	244 (0.02%)	0.93	226.92	0.0	0
17	1245 (0.83%)	1.04	1294.80	0.0	0
18	4134 (2.9%)	1.65	6821.10	416.8 (6.12%)	44 (1.06%)
19	9935 (7.%)	2.14	21260.90	5857.9 (27.54%)	894 (9.0%)

Total Weighed Trucks = 141,412

Generated ESALs = 191,120.19

ESAL Factor for all Trucks = 1.35

ESALs generated by heavy trucks = 169,870.61 (88.9 %)

ESAL factor for heavy vehicles = 1.9

Overloads

ESALs from overloaded trucks = 33,507.9 ESALs (17.5%)

Percent trucks overloaded = 3.4 %

Table 4.6

SUMMARY OF GROSS HEAVY TRUCK OVERLOADS

TRUCK TYPE	1986 % Heavy trks	1986 % ESAL	1989 % Heavy trks	1989 % ESAL
5 axle (types 9,10,11)	2.1	10.5	2.7	9.6
6 axle (types 12,13)	0.2	1.0	0.4	1.7
7 axle (types 14,15 ,16)	0.3	2.0	0.7	3.4
8 axle (type 17,18)	0.01	0.01	0.05	0.25
undefined axles (type 19)	0.01	0.18	1.0	3.40
TOTAL	2.62	13.7	4.9	18.33

Table 4.7

Proportion of Axles Overloaded

AXLES	PERCENT OVERLOADS WITHIN AXLE CATEGORIES 1986	1989
Front steering axles	0.01 - 2.5	4.3
Single axles	0.60 - 4.6	2.3
Tandem axles	1.00 - 8.9	7.3
Tridem axles	0.10 - 0.59	12.5

Table 4.8

ESAL Factors Of Trucks Within Lanes

Truck Type	ESAL Factor OUTSIDE LANE	C.V.*	ESAL Factor INSIDE LANE	C.V.*
3	0.18	0.24	0.31	0.44
4	0.98	0.23	1.28	0.23
5	0.28	0.41	0.28	0.74
6	-	-	-	-
7	0.42	0.28	1.55	0.87
8	0.57	0.32	1.18	0.80
9	1.54	0.21	3.33	0.21
10	0.72	0.83	2.35	0.55
11	1.28	0.33	1.86	0.67
12	3.64	0.29	6.26	0.52
13	0.79	0.26	2.71	0.85
14	2.30	0.24	5.01	0.56
15	2.15	0.20	5.08	0.53
16	0.93	0.42	1.3	-
17	0.94	0.28	2.42	0.38
18	1.57	0.27	3.89	0.58
19	1.93	0.23	4.24	0.59

* C.V. is coefficient of variation (Standard deviation divided by average)

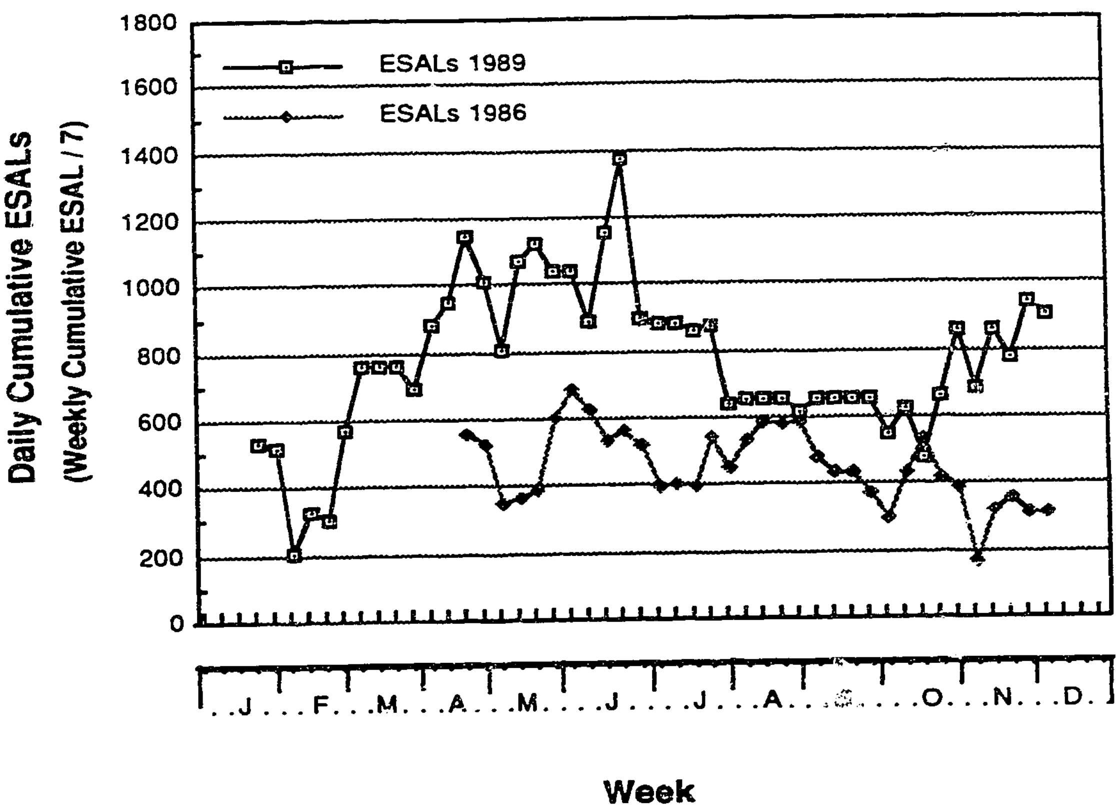


Figure 4.1 Variation in daily cumulative ESALs for 1986 and 1989
(ESALs of missed vehicles not included)

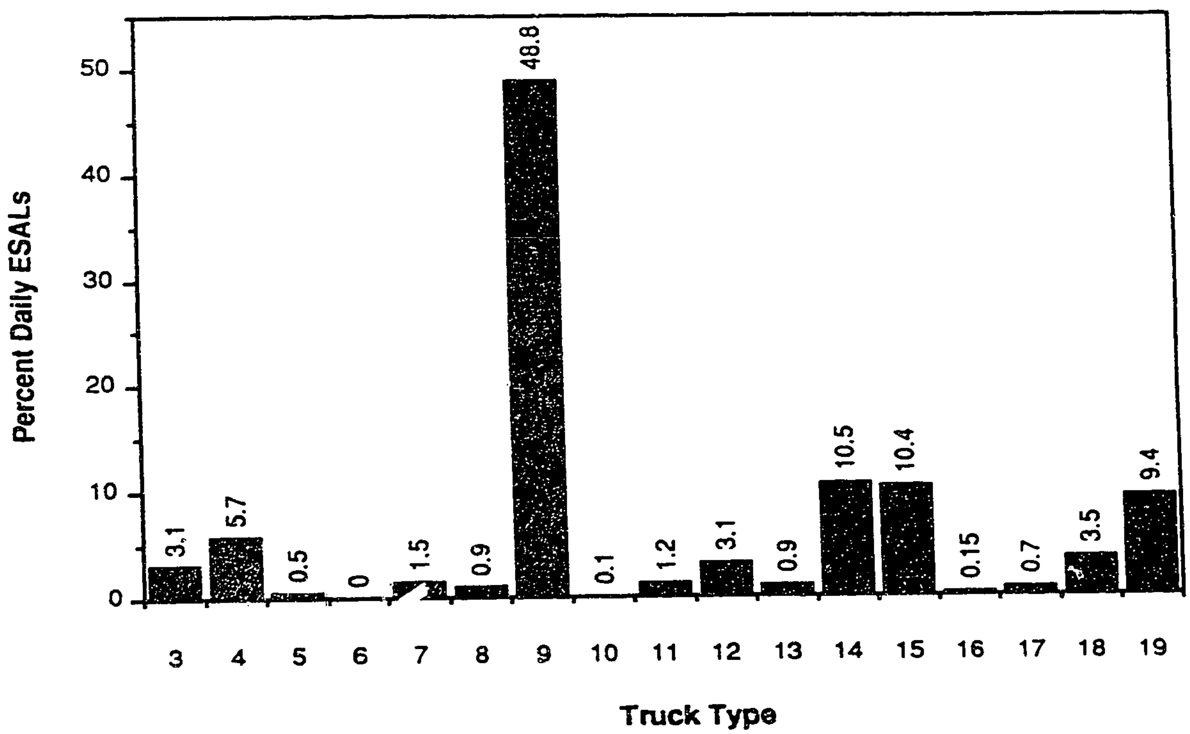


Figure 4.2 Proportion of Daily ESALs Generated by truck types

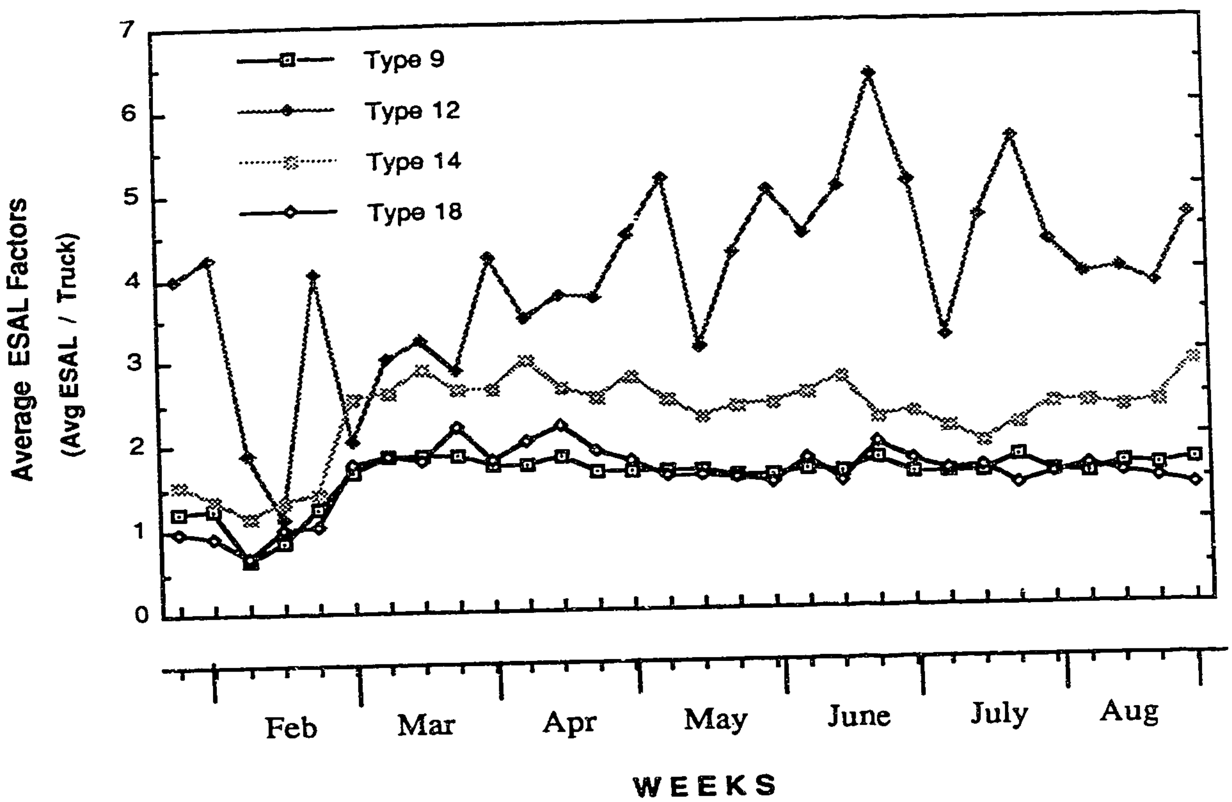


Figure 4.3 ESAL Factor fluctuations for Heavy trucks

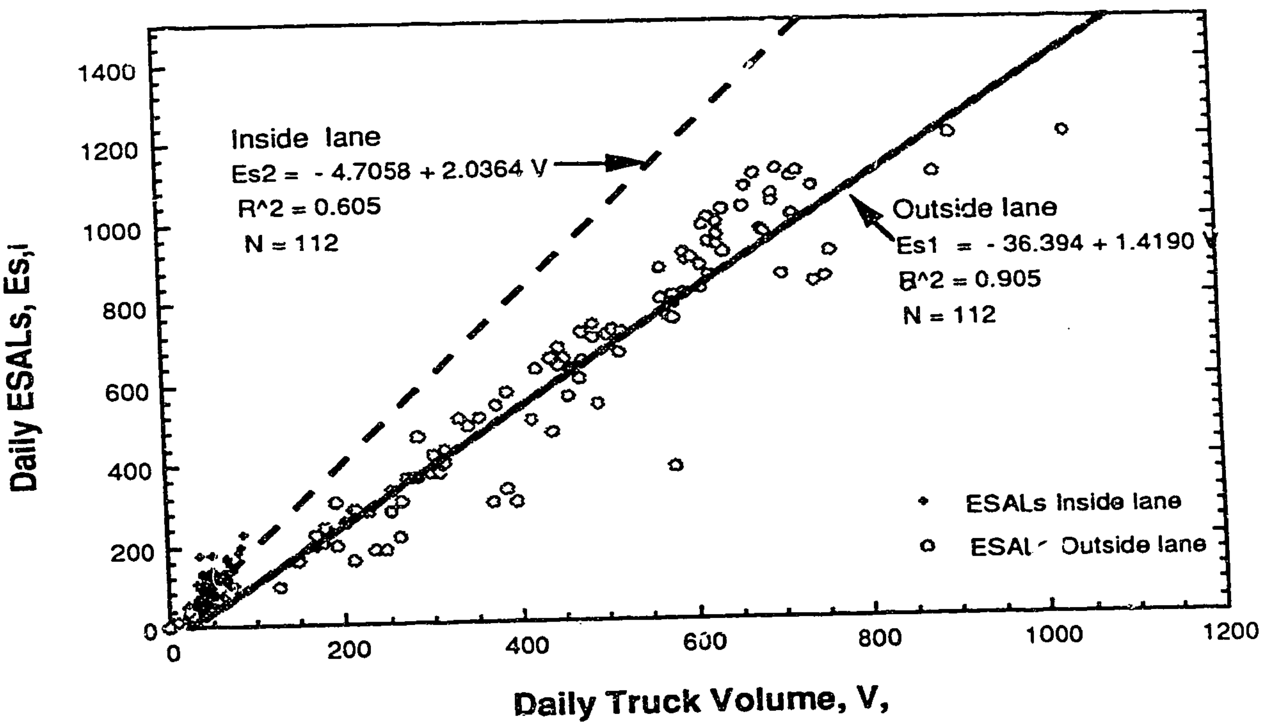


Figure 4.4 Daily Cumulative ESAL versus Truck Volume Relationship for both lanes

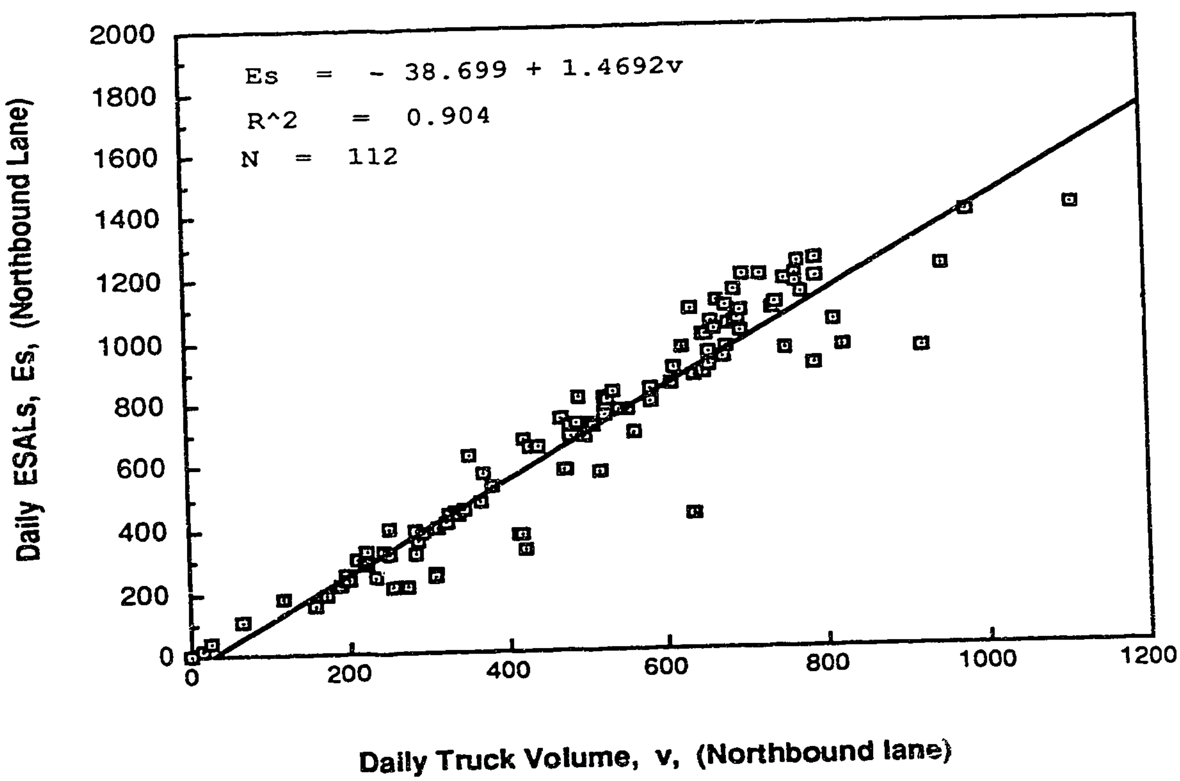


Figure 4.5 Daily ESAL and Truck Volume Relationship All North bound Lanes

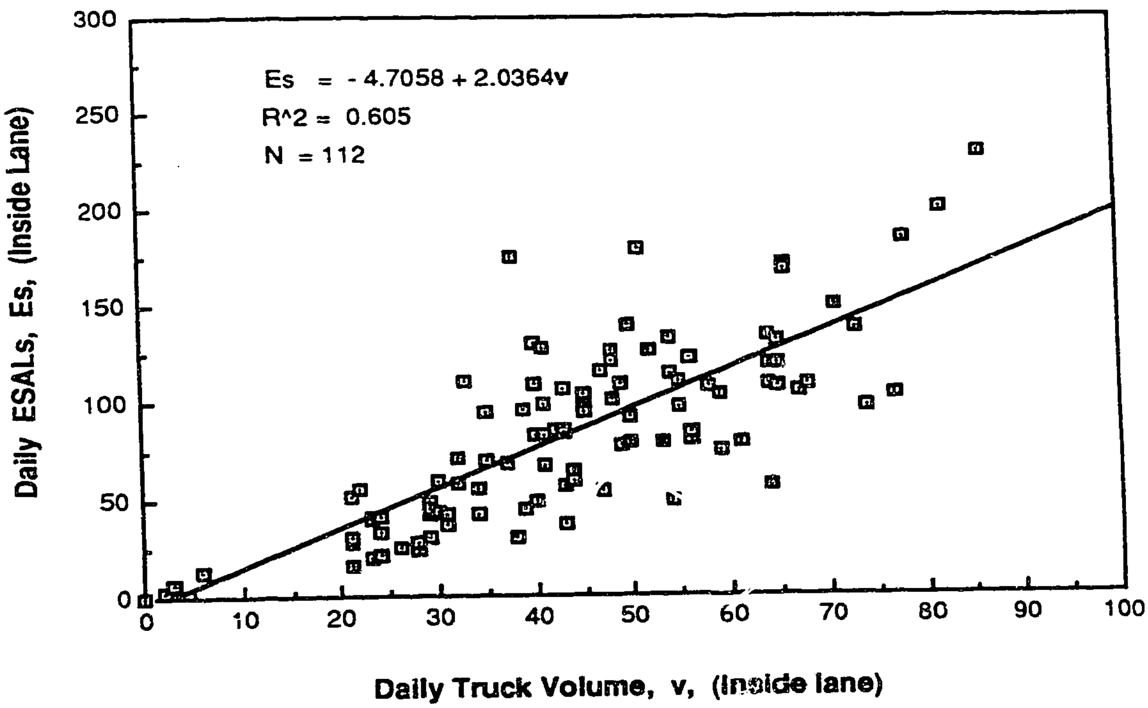


Figure 4.6 Daily ESALs and Truck Volume Relationship for Inside lane

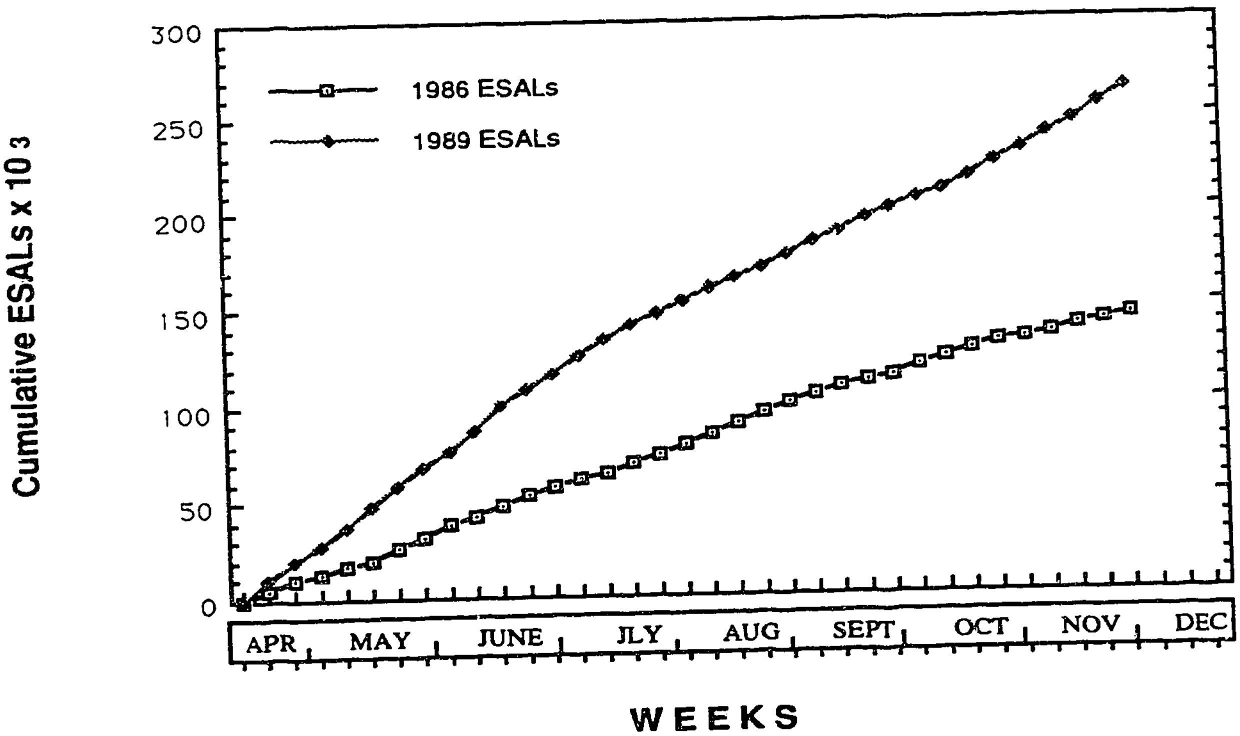
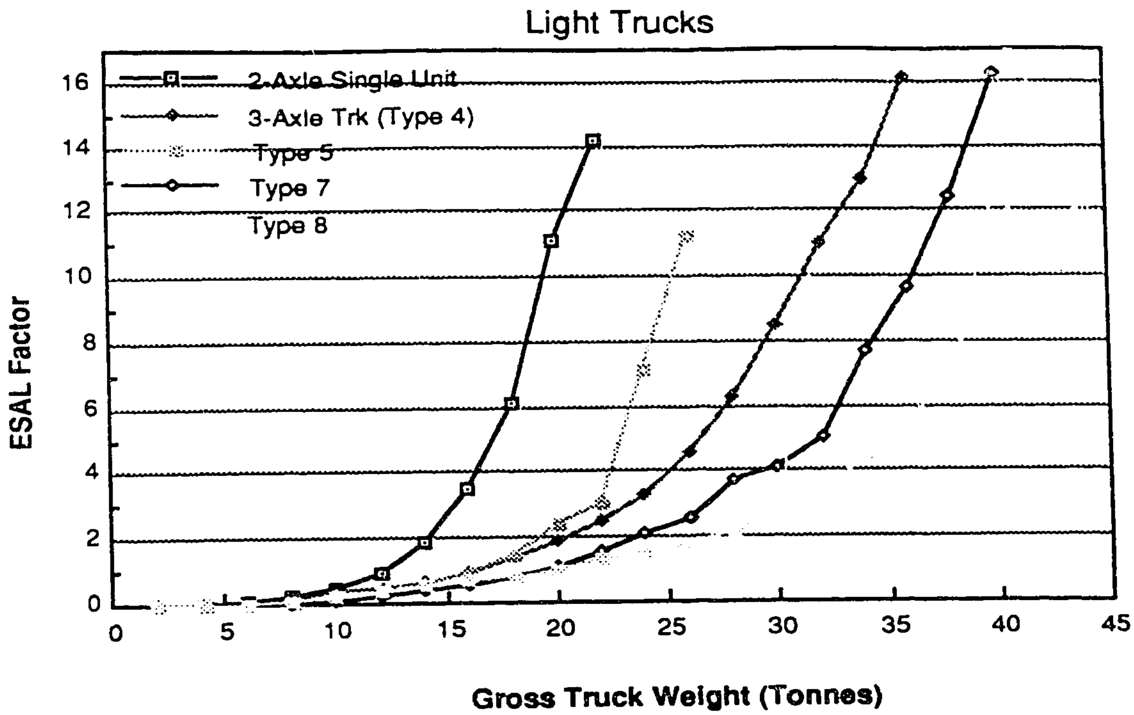


Figure 4.7 Cumulative ESALs Generated in 1986 and 1989



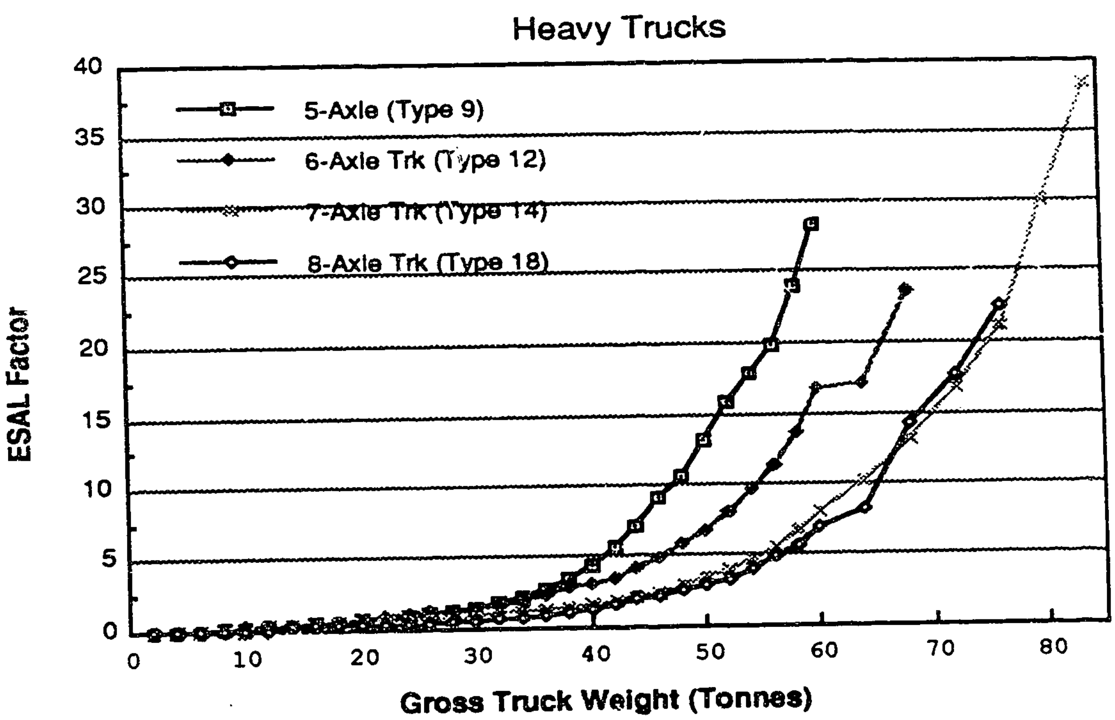
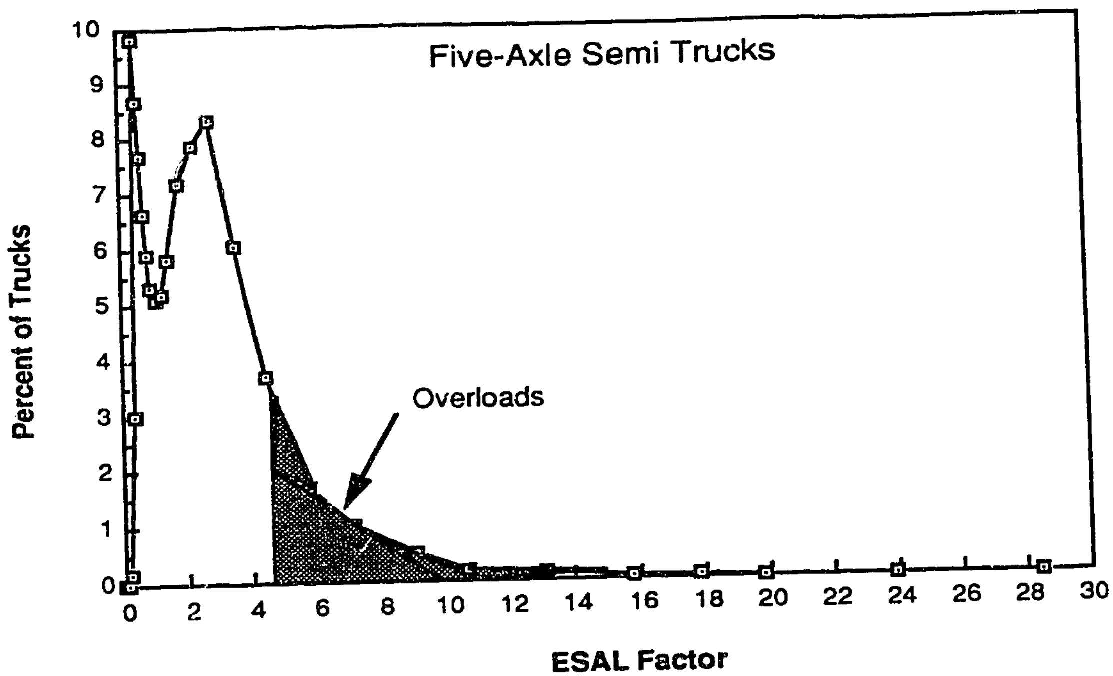


Figure 4.8 Relative Damage by Gross Vehicle Weights



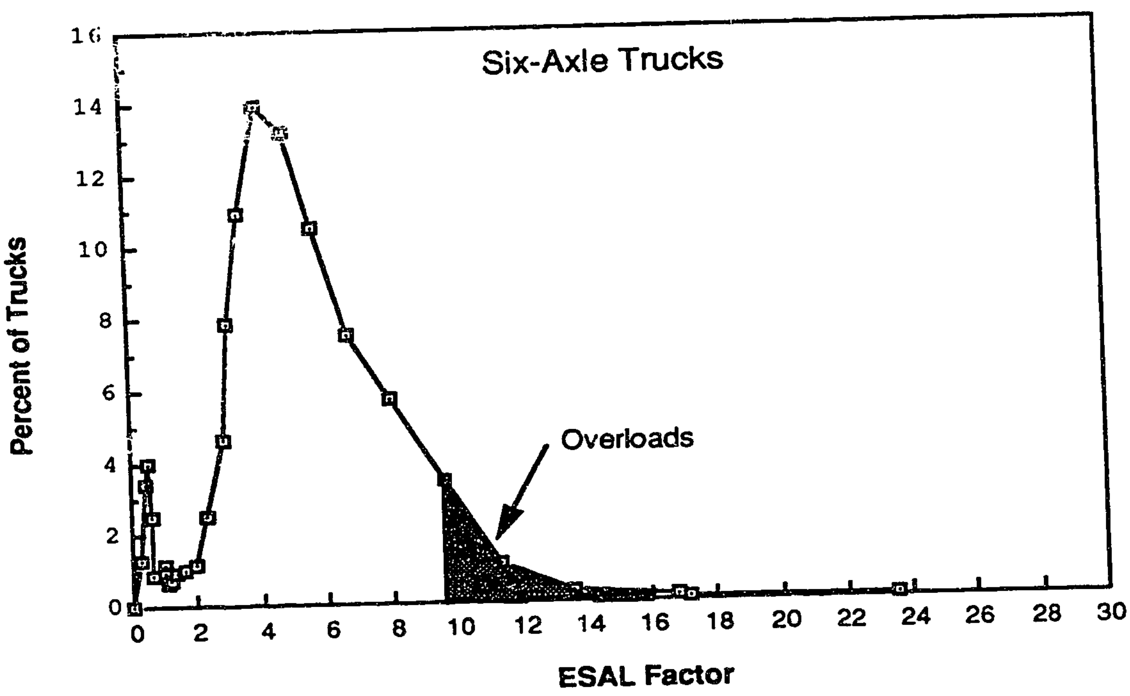
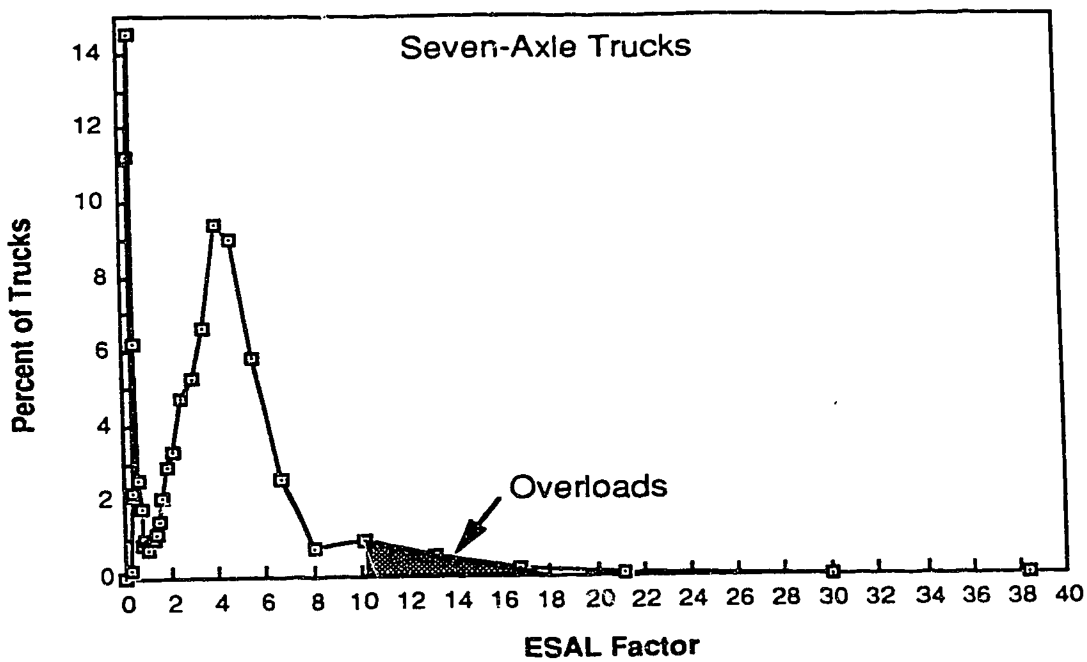


Figure 4.9 (a) Distribution of Trucks versus ESAL Factors (Five and Six Axle Trucks)



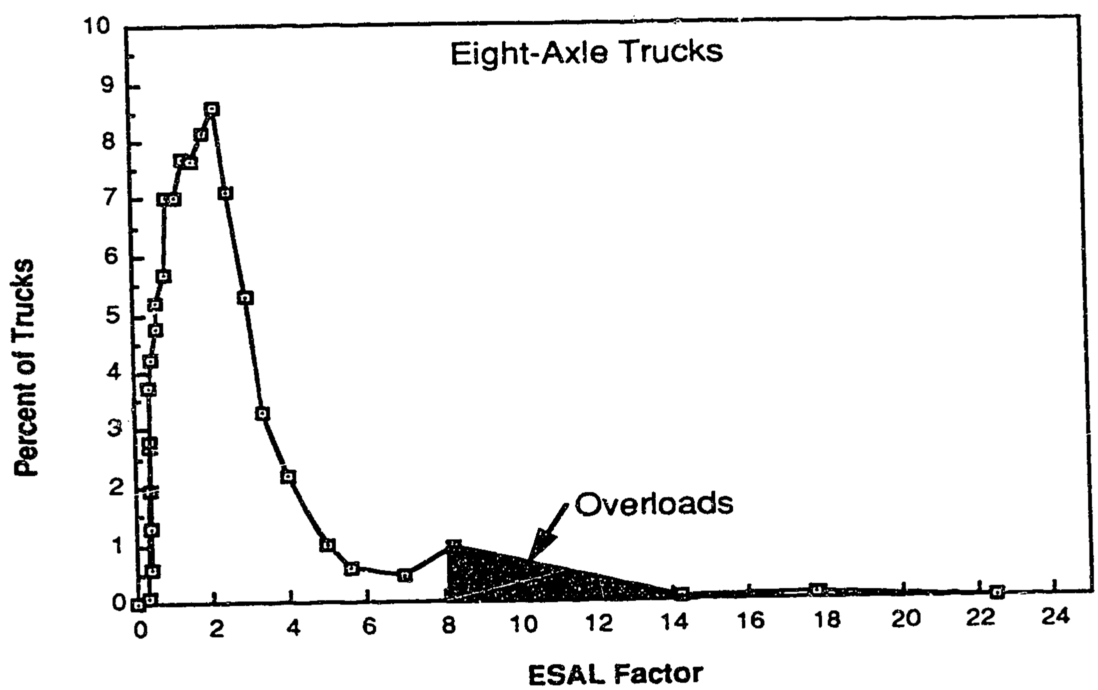
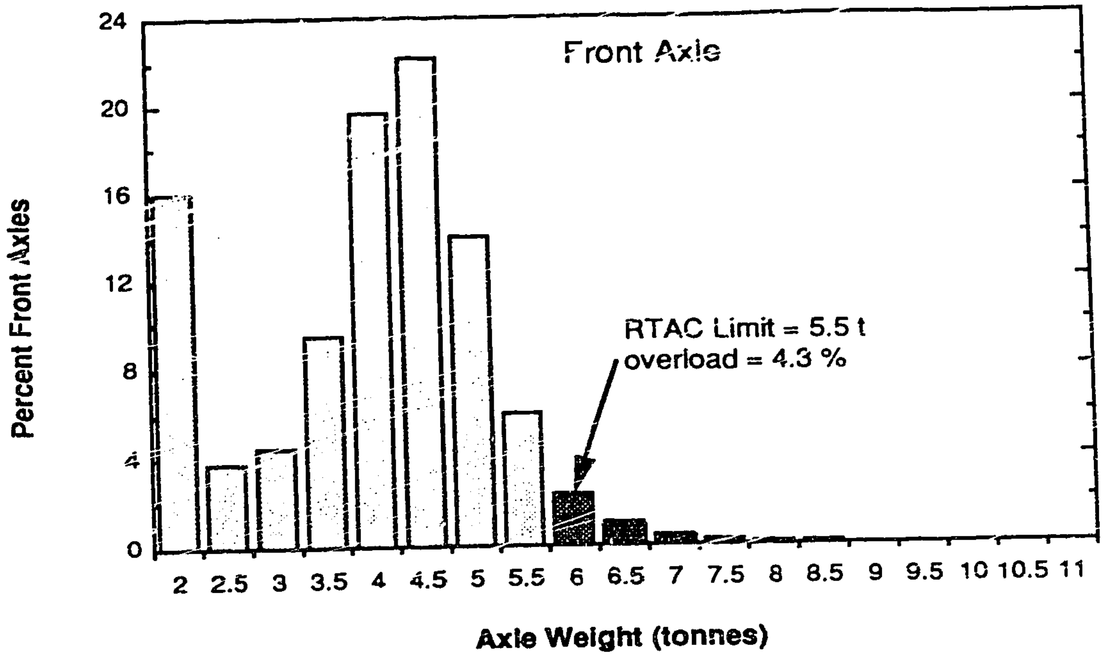


Figure 4.9 (b) Distribution of Trucks versus ESAL Factors (Seven and Eight Axle Trucks)



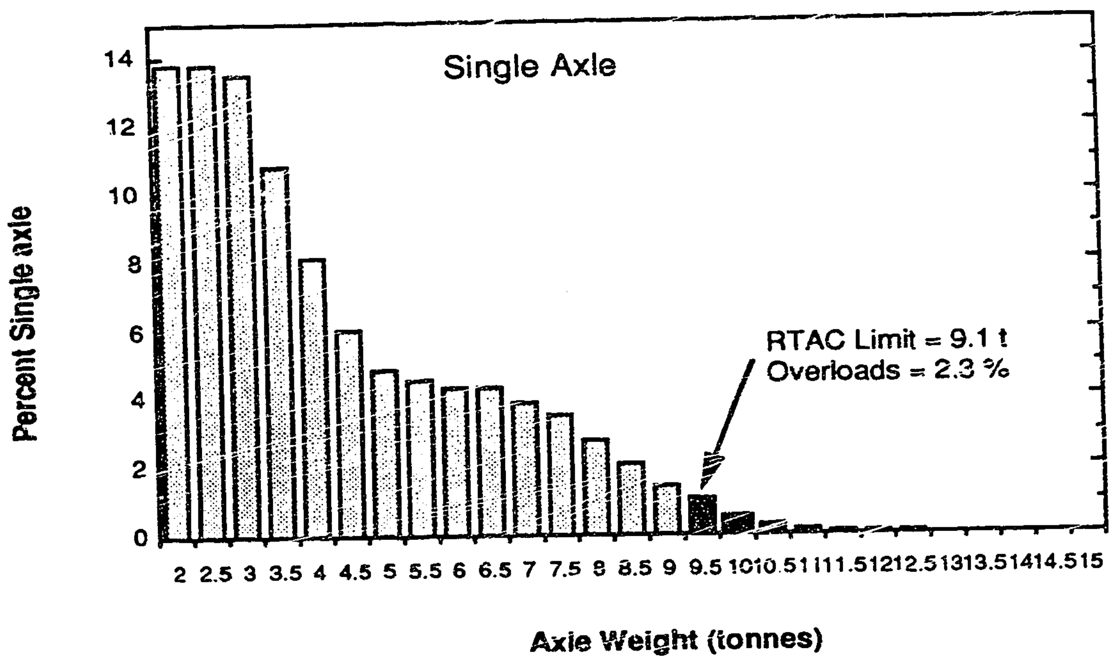


Figure 4.10 (a) Distribution of Front and Single Axles

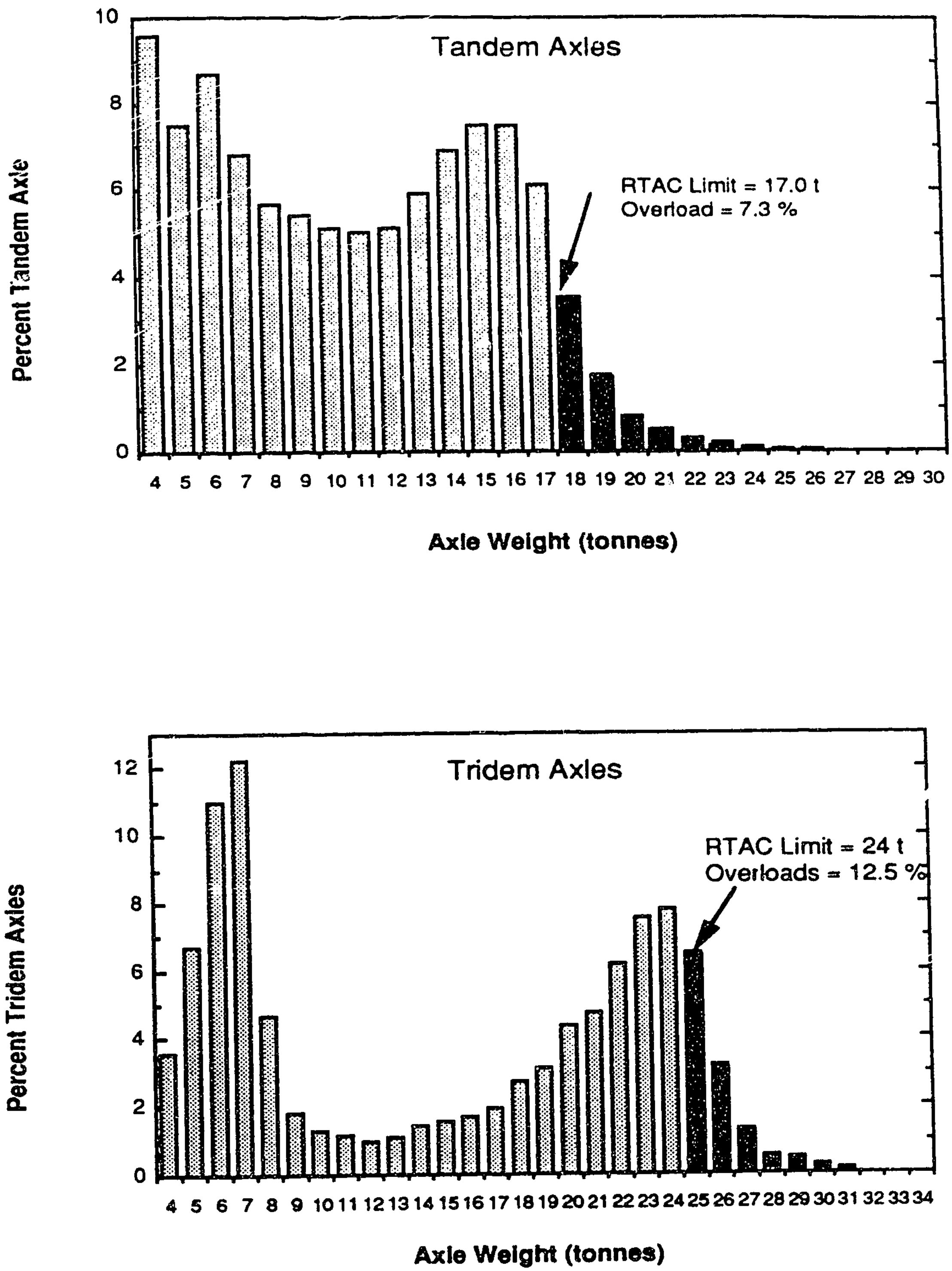


Figure 4.10 (b) Distribution of Tandem and Tridem Axles

CHAPTER 5

DESIGN IMPACTS OF WEIGHT CHANGES

5.1. Introduction

Changes in the distribution of gross vehicle weights (GVW), and different axle arrangements on trucks together increase the wear impact on the service life of pavements. Analysis of truck weight data before and after the RTAC weight changes described in the preceding chapters has shown the sharp increases in truck axle loads and corresponding increases in the damage units to the pavement.

Unlike other weight regulatory scenarios which are based on limiting the stress imposed by axle weights of trucks on highway bridges, the RTAC weight recommendations in 1988 called for higher gross vehicle weights based on minimum axle spacing. The estimated impacts of the changes, in terms of highway pavement thickness requirement, is reviewed in this chapter.

Although the main impact of the increased loading will be reflected in increased rehabilitation of the existing pavement, this study reports the impact of the weight changes in terms of the estimated pavement thickness requirement (flexible and rigid) resulting from the increase in truck loading demand.

5.2. Flexible Pavements

Flexible pavement design procedures require pavement structures to be designed for expected axle loads, traffic frequency and load distribution which are accounted for through equivalency factors.

5.2.1. Damage Mechanism

The damage mechanism involved when a wheel load is applied to a flexible pavement surface is explained briefly. An applied wheel load to the flexible pavement structure causes compressive vertical and horizontal stress distributions directly under the applied wheel. Compressive vertical stresses are known to be maximum under the wheel load and decrease with increasing pavement depth. Horizontal stresses also occur directly under the wheel load and can be tensile or compressive (Yoder and Witzczak 1975).

The design of flexible pavement thickness is generally based on limiting the associating strain criteria to these stresses. The horizontal and vertical strains are limited below those that will cause excessive cracking and permanent deformation to the pavement.

These criteria are considered in terms of repeated load applications since it is known that the accumulated repetition of traffic loads are of significant influence to the development of cracks and permanent deformation of a flexible pavement structure.

The equivalent single axle load (ESAL) repetitions analyzed in the preceding chapters are used to determine the full depth asphalt layer thickness which will withstand the increased stresses induced by increased load repetitions after the recommendations in 1988. Destructive effects of overloading trucks and axles are also translated into required equivalent pavement thickness.

The design analysis is based on the Asphalt Institute method of flexible pavement thickness design (Asphalt Institute, 1981). The procedures of the Asphalt Institute estimate pavement thickness to support the cumulative wear effects of trucks in terms of 18-kip (80-kN) equivalent single-axle loads (ESALs).

5.2.2. The Asphalt Institute Design Method

With the Asphalt Institute design method, the pavement is represented as a multilayered elastic system. Wheel loads from trucks are assumed to be applied as uniform vertical pressure which is then spread by the different components of the pavement structure and eventually applied on the subgrade at a much lower stress. Thickness design charts for the method have been developed based on limiting specific stress-strain conditions occurring within the pavement structure. The criteria are those of limiting the maximum applied tensile strains due to the deflection caused by the wheel load at the bottom of the Asphalt layer and reducing the maximum vertical strain at the top of the subgrade layer within the depth of the pavement structure.

5.2.2.1. Design Principle

The design principle is to determine the minimum thickness of pavement layer that will adequately withstand the maximum compressive strain at the surface of the subgrade and the horizontal tensile strain at the bottom of the asphalt layers. Design charts have been prepared for a range of traffic loads encountered in practice.

5.2.3. Full-Depth Asphalt Thickness

The combined effect of the RTAC weight changes is assessed in terms of an equivalent flexible pavement thickness. A full-depth asphalt thickness design option is used in such an analysis.

Based on the type and resilient modulus (M_r) of the supporting base and/or subbase, the minimum thickness of full depth asphalt required for the design ESAL is obtained by entering the appropriate table or chart available from the Asphalt Institute design manual. A sample chart for full depth Asphalt thickness design is reproduced as Figure 5.1.

5.2.3.1. Design ESALs

ESAL factors for trucks on the highway and truck volume analysis were presented in Chapters 3 and 4.

Assuming the traffic mix on highway 2 does not change throughout the selected service life of the pavement and using a general annual traffic growth rate of 4 percent the design ESALs for the design period is determined. A design period of 20 years is assumed for the analysis. As noted in the analysis of the WIM data, there was a sharp increase in truck traffic activities after the weight limit changes. Truck traffic growth rate between 1986 and 1989 translated to 10.8 percent. This growth rate is not used in the thickness analysis because of its short term nature.

A tabular format showing how the required design ESALs input to the Asphalt Institute method is determined is demonstrated in Table 5.1. Truck traffic volumes for 1989 are used in this table.

The total number of trucks in each category at the end of the first year (1989) is tabulated in column 1. These values are obtained using a design lane factor of 0.9. As an example, the number of type 3 truck category (2 axle single-unit trucks) at the end of the first year is

ADTT x 365 days x percent trucks x Lane factor x dir. split

$$= 1720 \times 365 \times 0.17 \times 0.9 \times 0.5$$

$$= 48{,}027$$

The growth factor in column 3 is calculated using the annual traffic growth rate of 4 percent. The growth factor expression is

$$[(1+r)^n - 1]/r,$$

where

r = rate/100 and

n = design period

Accumulated ESALs for the 20 year design period for all truck types summed up to 12.22 x 10^6 ESALs.

5.2.4. Damage Effects from Overloads

As discussed in chapter 2, pavement damage by heavy trucks increases sharply with the magnitude of the axle weight. Destructive effects of axle weights relates approximately to a fourth power relationship derived in the AASHO test. Overloaded trucks therefore results in greater damaging effects on the pavement. Although heavier trucks can carry the same amount of freight in fewer trips, the reduction in truck number offsets only a part of the added pavement wear effects of these trucks.
Overloaded truck effects on the highway pavement is interpreted by the proportion of total ESALs contributed by the overloaded axles of trucks.

5.2.4.1. Design ESAL Contribution from Overloaded Trucks

Using the percent gross truck overloads in 1989, accumulated ESALs due to overloads expected within the 20 years design period is calculated. A tabulation presentation is shown in table 5.2. Total ESALs from overloading at the end of the design period will be 2.07 x 10^6. Assuming no change in the current loading pattern, this will mean a 16.9 percent of accumulated destructive units on the pavement.

5.2.5. Flexible Pavement Thickness Calculations

The minimum thickness required for the design ESALs is obtained by using the chart in Figure 5.1. This chart is taken from the Asphalt Institute's Pavement Design Manual (MS-1) and shows the chart for a full-depth Asphalt Concrete thickness.

For the purpose of this analysis, an average Subgrade Resilient Modulus of 30 MPa is assumed.

Using the chart, the minimum required full-depth asphalt thickness for the design ESALs of 12.22 x 10^6 is 390 mm. Elimination of the overloaded ESALs of 2.07 x 10^6 through strict weight enforcement, will produce a required asphalt thickness of 380 mm. Thus overloading of trucks can be said to contribute an additional full depth asphalt thickness of 10mm.

5.2.6. Effect of Changes

The effect of the RTAC changes in terms of required pavement thickness is assessed by considering truck loadings before the changes. The design ESAL calculated by using 1986 data as the initial year is shown in Table 5.3. The total cumulative ESALs at the end of a 20 year design period is 7.14×10^6. Pre-RTAC truck loadings results in a full depth asphalt thickness of 360 mm. From these analysis, it can be concluded that the weight changes will translate into an additional full depth asphalt thickness of 30mm.

5.3. Rigid Pavements

To illustrate the use of axle load distribution on the highway for the design of rigid pavements, the Portland Cement Association's (PCA) method of pavement design is used. This method utilizes as its traffic data input the expected distribution of axle loads by axle configurations within the design life of the pavement (PCA 1984). The PCA recommends two design procedures. One based on when detailed axle-load distribution data is available and the other, a simplified approach, is used when detailed axle-load data is not available. The method is based on categories of representative loading data for different types of pavements. In this chapter, the detailed axle load distribution data analyzed in chapter 4 is used as input data to the PCA design approach presented.

The microcomputer design program, PCAPAV, is used to evaluate the thickness of pavement required to support the distributed loading for two different design periods of 20 and 40 years.

Design considerations such as the subgrade and subbase modulus and flexural strength of concrete are assumed to reflect a medium strength support and concrete strength. The influence of the provision of shoulders or no shoulders and type of joint on pavement thickness is analyzed. Comparisons are made on the basis of the resulting rigid pavement thicknesses.

5.3.1. The PCA method

The Portland Cement Association (PCA) design procedures involve the determination of pavement thickness adequate to carry traffic loading on concrete streets, roads and highways, within a specified design period.
The design approach is applied to plain, doweled, reinforced and continuosly reinforced concrete pavements.
Essentially the procedure relies on the strength (k value) of the underlying subgrade and subbase and the concrete flexural strength to evaluate the following criteria:

1. A "fatigue criteria" to keep induced pavement stresses from repeated axle loads within safe limits and thus prevent fatigue cracking;

2. An "erosion criteria" to limit the effect of pavement deflection at slab edges, joints and corners and thus control erosion pumping and faulting of foundation and shoulder materials.

The controlling failure criteria depends on the traffic intensity and the jointing type used.

5.3.2. Factors Considered in Analysis

The selection of an adequate pavement thickness involves the consideration of various input design parameters which include the axle load distribution of truck traffic. Other factors are the type of joint and shoulder used, the flexural strength of concrete, the subgrade and subbase support strength and the design life.

5.3.2.1. Type of Joint And Shoulder

The joint type used between sections of concrete slabs depends on the adequacy and/or degree of load transfer required, the effectiveness of joint sealants and the prevention of joint distress due to infiltration (PCA, 1984). Two joint types considered are doweled and aggregate interlock joints.

Doweled joints involve the installation of smooth steel dowel bars which serve as load transfer devices at each contraction joint. These are widely used in plain doweled pavements and reinforced pavement constructions. Contraction joint spacing, using doweled joints are recommended to be set at 6.6 m maximum for plain doweled pavements and 13.0 m for reinforced pavements. Joint spacings of greater distances will reduce the efficiency of the aggregate interlock transfer at the joints and and faulting will be accelerated.

Aggregate interlock joints are used at the joints of plain pavements. Load transfer is effected by the interlocking action of aggregates between the cracked faces below the joint groove.

The provision of concrete shoulders adjacent to the pavement reduce the flexural stresses and deflections caused by vehicle loads. The supporting action provided by shoulders acts as buttress to the pavement and prevent edges from curling up thus resulting in a reduction in pavement thickness required. Concrete shoulders also provide somewhat better serviceability for the same mainline pavement thickness.

5.3.2.2. Flexural Strength of Concrete

The ratio of flexural stress to flexural strength of concrete is the influencing property used in slab thickness design as opposed to the compressive stress components. The test results at the end of 28 days using the Modulus of Rupture test are used as the design strength input for concrete flexural strength in the PCA design procedure. For good quality concrete using normal aggregate, the average flexural strength ranges from 4.1 to 4.4 MPa (595 to 640 psi). Concrete Modulus of rupture of 3.8 MPa (550 psi) could be used in situations where the available aggregate type allows the production of concrete of such ultimate strength magnitude. In this chapter, MR of 4.1 MPa (600 psi) representing a medium flexural strength concrete with adequate durability and scale resistance are used in the design runs.

5.3.2.3. Subgrade and Subbase Support

The quality of the underlying support to a concrete pavement is one significant variable influencing thickness design of rigid pavements. Subgrade and subbase support strength are measured in terms of the Westergaard modulus of subgrade reaction (k) expressed as mega-pascals per meter (MPa/m). Subbase supports can be untreated or treated with cement and other appropriate stabilization methods which give equivalent quality of underlying support. The use of subbase materials on subgrades has the effect of increasing the *k* values of the underlying support. A cement treated subbase could result in over 300 percent increase in combined subgrade/subbase *k* value than that of an untreated granular subbase.

Subgrade *k* values depend on the soil type. Fine-grained soils with predominant silt and clay size particles have low strength. The average *k* values for such soils range from 20-

34 MPa/m (74-125 pci). Sands and sand gravel mixtures which are relatively free of plastic fines have high subgrade strength of 50-60 MPa/m (185-221 pci) k values. For the purpose of the present analyses a combined subgrade-subbase *k* value of 40 MPa/m (150 pci) is used for the supporting strength values in the PCAPAV input. This represents a medium strength fine-grained subgrade soil in which silt and clay size particles predominate with an overlying 100 mm thickness of untreated granular subbase material.

5.3.2.4. Projection Factors

Using an annual traffic growth rate of 4 percent the traffic projection factors are applied to the ADTT for the design truck volumes. Projection factors of 1.5 and 2.2 are used for the 20 years and 40 years design periods respectively.

5.3.2.5. Load Safety Factors

Unpredicted heavy truck loads and axle loads which occur through overloading of trucks require that a safety factor be incorporated in the axle load data. Load safety factor (LSF) of 1.2 are used for inter-provincial and other multilane highways which carry uninterrupted traffic flow and high volumes of truck traffic. LSF also serves to provide a greater allowance for the possibility of higher levels of pavement serviceability appropriate for higher type pavement facilities.

5.3.2.6. **Design Life**

The design life is the span in years required for the initial Riding Comfort Index (RCI) to be reduced to some specified terminal RCI or fault limit, at which time major maintenance, overlay, or grinding would be required. Rigid pavement thicknesses using design periods of 20 and 40 years have been used in the sample PCAPAV analysis.

5.3.2.7. **Axle Load Distribution Adjustments**

The distribution of axle loads have been adjusted to account for two-axle single unit trucks (type 3 trucks) which form 18 percent of all trucks weighed at the site. This truck type contribute very little damaging units to the road pavement. Adjustments are made to eliminate their influence on truck number in designing pavements.

5.3.3. **Thickness design with the PCA Software (PCAPAV)**

Using the PCA design software for rigid pavements, requires the input of the above discussed parameters. The required pavement thickness and the criteria for failure under the expected axle load repetitions is the output obtained from the program. In appendix B, outputs of the PCAPAV program for the various design alternatives considered are shown. This appendix is meant to illustrate the use of axle load distribution at the weigh scale site for concrete pavement design.

5.3.3.1. Tridem Axles

The PCAPAV program does not incorporate the load distribution of tridem axles. The influence of tridem axles distribution is determined by the manual procedure of the PCA (PCA 1984). It was found in the analysis that current loading for tridems on highway 2, does not influence the pavement thickness obtained by considering only single and tandem axle distributions.

5.3.4. Failure Criteria

Rigid pavement thickness alternatives obtained by a combination of shoulder and joint types is summarized in Table 5.4. The criteria for failure for these joint combinations and two design periods is also shown. The presented truck intensity and axle distribution shows erosion damage to be the controlling failure criteria. An "erosion criteria" limits the effect of pavement deflection at slab edges, joints and corners and thus control erosion pumping and faulting of foundation and shoulder materials.

5.4. Changes in Gross Vehicle Weights

The direct impact of the RTAC weight limit changes is the increase in truck gross loading and corresponding increases in ESALs. The increase in truck gross loading implies increased destructive action which translates into the provision of thicker pavement structures and reduced rehabilitation period for existing pavements. There were also changes in truck axle configuration and arrangements on the highway following the introduction of standard truck types by RTAC.

5.5. Changes in Average Axle Weights

The average registered weights of each axle type for 1986 and 1989 was shown in table 4.3. Loading on all axle categories increased except for the front tandem axle groups which saw a reduction in weight by about 17 percent from 11.2 tonnes to 9.3 tonnes. Average weights of tridem axles increased significantly by 90 percent. These axle types represented 1.5 percent of 1989 registered axles as compared to 0.2 percent recorded in 1986.
The overall average weight of axles increased by 5.2 tonnes (14.4 percent increase).

5.6. Changes in Truck Axle Configuration

The arrangements of axles on trucks influence the distribution of truck payload among the axle groups and hence the resulting destructive nature of axle loading on highway structures measured in ESALs.

When axles are arranged closer together, internal stresses impacted to the pavement structure from each axle begin to overlap, thus ceasing to act as separate entities. Reduced axle spacing leads to increased maximum deflection of the pavement surface but decreases the maximum tensile stresses at the underside of the surface layer, a primary cause of fatigue cracking in pavements (Yoder and Witzczak, 1975)

The RTAC recommendations introduced the use of the B-train truck which encouraged the use of tridem axle sets. The shift to the use of more tridems is evidenced in the increased proportion of these axle configuration in the 1989 analyzed data. As discussed in the preceding section there was a dramatic increase in tridems after the introduction of the B-train. Also, there was a shift in trucking activities to the use of trucks with tridem axles which is reflected in the higher average weight of these axle types.

5.7. Conclusions

This chapter has illustrated the use of analyzed load data from WIM scales in both flexible and rigid pavement design requirements. The RTAC weight changes will translate into an additional flexible pavement depth of 30 mm over a projected 20 year period in central Alberta.

Overweight vehicles contribute about 17 percent of the destructive loadings from traffic. This translates to a 10mm flexible layer thickness.

Erosion damage is found to control the failure criteria of an alternative rigid pavement.

Table 5.1

Tabular Calculation of Design ESAL for Asphalt Design (1989)

Truck Type	*No. of weighed trucks (1)*	*ESAL Factor (2)*	*Growth Factor. 4 percent Annual growth (3)*	*ESAL(1x2x3) (4)*
3	48027	0.21	29.78	300351
4	18646	1.05	29.78	583042
5	4521	0.29	29.78	39044
6	36	0.65	29.78	697
7	9322	0.47	29.78	130476
8	4238	0.62	29.78	78249
9	112157	1.67	29.78	5577859
10	282	0.88	29.78	7390
11	4238	1.37	29.78	172905
12	2260	4.29	29.78	288729
13	3672	0.92	29.78	100604
14	20340	2.51	29.78	1520370
15	21754	2.41	29.78	1561280
16	847	0.93	29.78	23458
17	3107	1.04	29.78	96228
18	9322	1.65	29.78	458055
19	20058	2.14	29.78	1278280
Total				12.22×10^6

Table 5.2

Tabular Calculation of Design Overloaded ESALs (1989)

Vehicle Type	*No. of Overloaded Vehicles in design lane (1)*	*ESAL Factor for overloads (2)*	*Growth Factor (4 %) (3)*	*ESAL (1x2x3) (4)*
3	186	4.66	29.78	25812.11
4	447	5.39	29.78	71749.85
5	6	10.23	29.78	1827.90
6	0	0	29.78	0.00
7	39	10.37	29.78	12043.93
8	56	6.07	29.78	10122.82
9	4935	6.78	29.78	996417.95
10	7	11.08	29.78	2309.74
11	105	7.14	29.78	22326.07
12	588	7.48	29.78	130979.59
13	22	8.35	29.78	5470.59
14	1033	8.80	29.78	270712.11
15	446	10.26	29.78	136272.09
16	0	0	29.78	0.00
17	0	0	29.78	0.00
18	99	9.47	29.78	27919.64
19	1805	6.55	29.78	352081.50
Total				2.07×10^6

Table 5.3

Tabular Calculation of design ESAL for Asphalt design (1986 loading)

Vehicle Type	*Number of Vehicles during 1st year (1)*	*ESAL Factor (2)*	*Growth Factor for 4 percent Annual growth (3)*	*ESAL(1x2x3) (4)*
3	36299	0.18	29.78	194577.16
4	14093	0.78	29.78	327357.84
5	3416	0.30	29.78	30518.54
6	212	0.40	29.78	2525.34
7	7046	0.53	29.78	111209.84
8	3203	0.80	29.78	76308.27
9	84769	1.32	29.78	3332235.48
10	213	0.36	29.78	2283.53
11	3203	1.18	29.78	112554.70
12	1708	2.71	29.78	137842.09
13	2775	0.82	29.78	67764.39
14	15373	1.87	29.78	856100.85
15	16442	1.84	29.78	900942.68
16	641	0.71	29.78	13553.18
17	2349	0.99	29.78	69253.69
18	7046	1.21	29.78	253894.15
19	15160	1.45	29.78	654623.96
Total				7.14×10^6

Table 5.4

THICKNESS ALTERNATIVES FOR 20 YEAR DESIGN PERIOD

	JOINT TYPE	
	Aggregate Interlock	**Dowels**
No Concrete shoulders	310 mm (12.5 ins) (erosion criteria)	250 mm (10.0 ins) (fatigue criteria)
With Concrete shoulders	260 mm (10.5 ins) (erosion criteria)	220 mm (8.5 ins) (fatigue criteria)

THICKNESS ALTERNATIVES FOR 40 YEAR DESIGN PERIOD

	JOINT TYPE	
	Aggregate Interlock	**Dowels**
No Concrete shoulders	370 mm (14.5 ins) (erosion criteria)	270 mm (10.5 ins) (erosion damage)
With Concrete shoulders	290 mm (11.5 ins) (erosion criteria)	230 mm (9.0 ins) (erosion criteria)

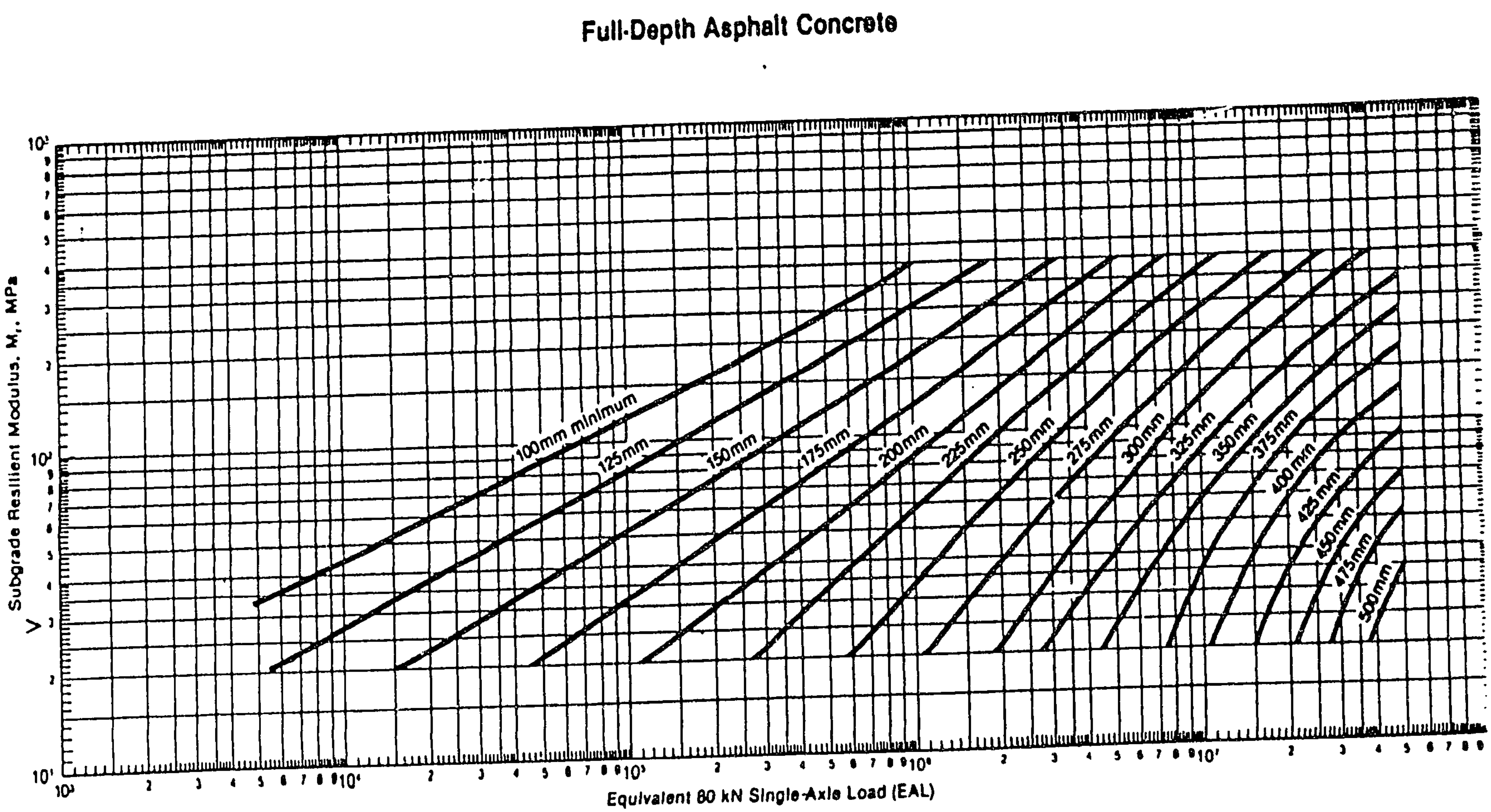


Figure 5.1 Pavement Designs for Various Traffic Loading Parameters

Source: Chart is from Asphalt Institute's Pavement Design Manual (MS-1)

CHAPTER 6

LANE CHOICE OF LEFT-TURNING TRUCKS

6.1 Introduction

Many traffic related factors and roadway geometric conditions affect the choice of lanes by trucks on multilane highways. The most significant of these factors can be identified as (a) the traffic volume on the road section at a particular time interval, (b) the speed attained by the main highway traffic stream, (c) the traffic composition on the roadway section, (d) the geometric layout of the roadway including the number and location of access points and, (e) regulations regarding the use of lanes by trucks.

Past studies on the lane-use pattern of trucks on freeways and divided multilane highways have shown that all trucks do not use the same lane for travel. The American Association of State Highway and Transportation Officials (AASHTO, 1986) have recommendations on the proportion of trucks in the lanes of multilane highways. It is suggested that between 60 to 100 percent of truck traffic use the outside right lane in travelling under a set of free flow conditions. The actual distribution varies with the number of lanes in one direction. This distribution is corroborated by the lane distribution equations presented in the Portland Cement Concrete Pavement Evaluation System (COPES) (Darter et al., 1985). In chapters 3 and 4 of this study, the distribution pattern at the weigh-in-motion site at Leduc, shows 90 percent distribution for the outside lane for the four lane divided highway.

The presence of heavy vehicles in the traffic stream also has reciprocating effects on the operating conditions of other vehicles. At intersections, truck turning movements, merging maneuvers and lane changes influence the operations of approaching traffic. This could lead to the possible formation of queues on the through road if turning truck traffic volumes are high. Also, the pressure of traffic demand on the main highway at an unsignalized intersection will influence the lane choice of turning truck traffic from an intersecting road.

Left-turning trucks from side roads generally encounter two or more lanes of opposing traffic streams. The number of conflicting traffic streams depend on the number of lanes on the main highway. The left-turning driver has to evaluate the gap sizes in these opposing streams and select an opening which he considers large enough to enter while he at the same time evaluates the lane to select based on the flow conditions on the highway.

The ultimate aim of most truck drivers, after negotiating a turn, is to move to the outside right lane in order to give way to fast approaching vehicles in the inside lanes. This shift from the inside lane to the outside lane takes place over a distance which depends on the influencing effects of main highway traffic conditions.

This section of the Thesis reports on a field study and evaluation of truck driver decisions and reactions when entering the main traffic stream of a multilane highway from a side road. The emphasis is on the lane changes and lane selection of trucks as they join a multilane highway segment and the travelled distance within which an equilibrium distribution of lane use is attained.

6.2 Objectives

In an effort to increase the understanding of truck lane distribution behavior on multilane highways, this part of the research seeks to investigate the following:

(i) The left-turn behavior of heavy vehicles onto a heavily travelled multilane highway and the corresponding effects on the operating characteristics of main highway traffic.

(ii) The lane choice and lane changing characteristics of left-turning truck traffic along the highway.

Other left-turning characteristics evaluated include:

1. The percent of trucks encroaching on the highway shoulders on turning.

2. The travelled distance from the intersection, at which a stable distribution of trucks across lanes is attained.

6.3 Terminology

Definition of the following terms is necessary for an understanding of the procedures and results of this studies.

A GAP, as defined by Wagner (1965) and Solberg (1965) is considered as the elapsed time between arrival of successive main street vehicles at a specified reference point in the intersection area.

A LAG is that portion of a current gap remaining when a side street vehicle arrives; in other words, the elapsed time between arrival of a side street vehicle and arrival of the next main street vehicle.

6.4. Field Studies

To evaluate the lane choice of left-turning trucks and to provide other data for verifying the lane distribution of trucks, the following variables were measured in the field studies:

1. Traffic volumes operating on the through multilane highway. Data was collected at 5 minute intervals.
2. Lane by lane classification of through vehicle by type along a section of multilane highway.
3. Waiting position of left-turning trucks.

4. Through lane selected by a turning truck.
5. Lane changes of turning trucks within the intersection area.
6. Incidences such as the use of shoulders by turning trucks.
7. Incidences such as the formation of queues on the intersecting road and the main highway.
8. Length of study period.
9. Platoon densities on highway at the time of a turn maneuver by a truck.

6.5 Site Selection

It was difficult to locate many intersections with all the desirable characteristics that was required for the study. However, with the overall objective of defining a representative distribution for the lane choice of turning truck traffic at multilane highway intersections, information on trucks entering a main stream of peak hour commuter-shed traffic was studied. The survey involved counting and observing the lane selection and lane changing maneuvers of trucks at the intersection of highway 16X and highway 794 including a 4 km section along highway 16X. The surveyed intersection is an unsignalized T-intersection with a posted stop sign on the minor highway (highway 794). Peak hour traffic consists of early morning commuter traffic and gravel-hauling truck traffic from highway 794.

6.5.1 Site Description

Highway 16X is a primary highway carrying high volumes of commuter-shed traffic travelling east to Edmonton in the mornings (peak hours 7:00-8:00 a.m). Posted speeds on most sections of this four lane divided highway is 100 km/h. At the surveyed intersection, 80 meter length auxiliary lanes added to through lanes transform cross-section widths at the section to six lanes. Shoulder widths of 1.5 meters and 3.0 meters board the median and outside lanes respectively. Average annual two way daily traffic (AADT) is reported in Alberta Transportation's "Traffic volume and vehicle class statistics" (Alberta Transportation and Utilities, 1989) as 15,640 with 19.7 percent heavy vehicle composition.

Highway 794 is a two lane secondary highway which joins Highway 16X to the north leading to the city of Villeneuve. The average annual daily traffic (AADT) on this road is 2,780 with trucks representing over 30 percent of the daily traffic. Trucks, exiting from this highway haul gravel from gravel pits for construction works in Edmonton and surrounding areas.

A schematic of the intersecting highways and test section is shown in Figure 6.1. The following criteria were used as a basis for selecting the site:

1. Turning truck volumes:- There must be a high truck turning volumes on the intersecting minor highway (truck weights not considered).

2. Highway geometry:- the through (main) highway must be multilaned and heavily travelled by traffic.

3. Control:- the intersection must be unsignalized and controlled by stop signs on the minor intersection.

6.6 DATA COLLECTION AND REDUCTION

6.6.1 Data Collection

Field data were collected for 5 days during the morning peak hour between 7:00 and 8:00. This included 2 days of preliminary survey used for observing left-turning truck traffic behavior at the intersection. Traffic flow rates and fluctuations on the main highway during the surveyed periods were such that acceptable gaps covered the full range, from gaps and lags so small as to be unacceptable, to those large enough to be acceptable by all trucks.

The survey team consisted of three observers, who collected data on traffic at both the intersection and along the main highway section (Highway 16X).

It was overcast but clear during the survey periods with good visibility along the stretch of highway.

The observation posts of two members of the survey team was changed on each survey day. This study method was resorted to because of the limitation in the number of observers who undertook the survey. The stationing of observers along the main highway on each survey-day were as follows:

	OBSERVER 1	2	3
Day 1 -	0.0 m	200 m	800 m
Day 2 -	0.0 m	800 m	2.0 km
Day 3 -	0.0 m	2.0 km	4.0 km

The intersection was chosen as the 0.0 metre post and all other observation posts were measured with respect to this station.

Traffic volumes and traffic lane use were recorded with tally boards having five push-buttons. These register the cumulative volume of vehicles when the buttons are actuated. The observers actuated the buttons to record, (a) the arrival of main highway vehicles in each lane along the main highway, (b) arrival of side road vehicles which had predominant truck volumes and (c) intersection entry of a truck from the side highway and the selected lane on turning. The cumulative vehicle counts were recorded at the end of each 5 minute period. Using this technique enabled the lane chosen by a truck on turning and the highway flow rate during a turning maneuver to be extracted from the compiled data. A total of three one hour sample data were collected during the survey.

The further two days preliminary observation survey at the intersection was aimed at safeguarding against overlooking or misinterpreting the significance of a driver's behavior or a traffic variable. This occurs when large traffic counts are obtained over long time frames and may submerge the real effects of other important traffic variables.

This two days observation survey involved the observation of truck behavior during left-turning maneuvers with varying traffic flow characteristics on the main highway. Truck and traffic characteristics observed included, truck lane choice on turning, lane placement of trucks before turning, lane and speed changes of through vehicles due to the influence of merging trucks, and other related traffic incidents such as queue formation and backups on the main highway. An attempt was made to exclude vans and pickups in the analysis since these vehicle types have almost the same influence on the traffic stream as passenger cars in accepting gaps (Noblitt 1959).

6.6.2 Patterns in 5 Minute Data Collection

The question of how turning truck traffic behaves during the transition from low flow volumes to high flow volumes on the multilane highway is complicated by the fact that data pattern is dependent on the size of the interval over which the data is averaged.

Variation in arrival pattern of traffic on the main highway within the chosen intervals of 5 minutes dampen the real effects of high flow rate traffic on merging trucks. Traffic variables such as speed, density, acceleration, lane use etc. within the 5 minute period could be the average over two or more quite different operating conditions.

To offset and make corrections for variations within the time frame, the two days observation survey was used to observe the merging and lane changing patterns with various through traffic densities within short time frames of 60 seconds or less. The analysis of data from the preliminary survey was found to describe the lane choice behavior of the left-turning trucks much better.

6.6.3 Data Reduction

The number of vehicles in an arriving platoon at the intersection during a turning maneuver by one or more trucks onto the main traffic stream were converted to flow rates per hour by the expression:

$$Q = 3600/t_i \cdot V_i$$

where

Q = through traffic flow rate in veh/hr. The flow values obtained were for both eastbound lanes.

t_i = the time interval between the moment a turning maneuver is initiated by a truck from its waiting position on the side road and the moment the turning maneuver is completed. The point of turn completion was taken as the end of the acceleration lane.

V_i = number of vehicles in a platoon on the main highway within the time interval that a truck initiates a turn from the minor highway.

The lane into which a truck turned, due to the influencing effect of through traffic flow rate were noted. Table 6.1 and Figure 6.2 show the distribution of selected lanes within a range of flow rates in the eastbound lanes.

6.6.4 Hourly Flow

The average hourly volume of the eastbound traffic for the three surveyed days was 1,750 vehicles/hour. There was little variation in volume between the surveyed days. This is due to the fact that the traffic stream consists mainly of daily commuters or frequent users during the morning weekday peak period.

Considering the short-term fluctuations in traffic flow rate a maximum 5-minute flow rate of 198 vehicle/5 min (2400 vph) is achieved. The peak hour factor, which relates the hourly volume and the peak 15-minute flow is 0.84.

6.7 Results

The field studies was aimed at defining a representative frequency distribution of the lane change and lane use patterns of left-turning truck traffic at the surveyed intersection. In addition an effort is made to determine the travelled distance over which an equilibrium lane distribution of trucks is attained. Shoulder encroachment by turning trucks and the impact of trucks on the operation of through traffic are also outlined.

6.7.1. Gap Types

Eight main types of gaps were defined for left-turning truck in the study. These gaps result from the flow of traffic in both directions on the main highway. Turning trucks could accept or reject offered gaps depending on the traffic situation. Four of the eight gap types are formed by successive inside and outside lane vehicles on the westbound two lanes nearest to the intercepting road. These gap types were not considered in the survey because trucks had the tendency of waiting at the median opening for an acceptable gap in the eastbound traffic stream. The four types of defined gaps considered were formed by successive inside or outside lane vehicles in the eastbound direction, or by vehicles which are offset in the two lanes. Figure 6.3 shows a diagrammatic illustration of the four defined gap types.

6.7.2 Lane Choice Types

At least five types of lane choice by trucks were observed within 80 meters of the intersection. Of these lane choice types, Two of these lane choice types were incidences forced on merging trucks by through traffic flow conditions. These are when trucks are forced to use the inside or outside shoulder for travel. The other lane choice options were the selection of one of the three normal lanes within the vicinity of the intersection which included the 80 meter long accelerating lane at the intersection.

6.7.3 Lane Choice on Turning

The lane selected by a truck on turning was found to depend highly on the flow rate of the through traffic during a left-turning maneuver. As shown in Table 6.1 and Figure 6.2, merging trucks either could not accept available gaps for a smooth entry into the traffic stream or were forced to use the inner shoulder lane for travel when flow rates exceeded 1,750 veh/hr/lane.

The survey also showed a strong relationship between the mean speed of an approaching platoon and the lane selected. Even though traffic speeds were not measured directly in this field studies, speed rating from visual observation supported this conclusion.

At lower flow rates less than 600 veh/hr/lane, trucks tend to cut across the accelerating and inside lanes onto the outside lane to merge on the outside lane. Such flow situations offered, enough gap and lag opportunities and the freedom to select lanes without restraint.

6.7.4 Shoulder Use

The use of either the inside or outside shoulder of the highway were incidences forced on turning trucks by the operating conditions of main highway traffic. As observed, 23 of 49 turning trucks using the acceleration lane continued on the inside shoulder for a considerable distance after reaching the end of the accelerating lane. Such trucks could not find an acceptable gap in the traffic stream within the 80 meter distance due to high traffic flows. There were fewer incidences of trucks using the outside shoulder on turning. Such incidences occurred when turning trucks cut quickly across to the outside lane to avoid an approaching platoon. Five instances of trucks encroaching on the outside lane on turning was recorded.

6.7.5 Turn Types And Starting Positions

For most left-turns at unsignalized intersections made under moderate to heavy traffic conditions, turning is undertaken from a stopped or waiting position within the intersection. This left-turning approach was typical of light vehicles. Observations of turn pattern at the surveyed intersection showed that most heavy trucks stopped well behind the intersection stop line for an acceptable gap opportunity in the westbound traffic. These trucks then entered the intersection and waited at the median opening for an acceptable gap in the eastbound traffic stream. Under relatively light traffic flow conditions, some trucks merged fully with the main traffic stream without stopping within the intersection.

Of the 196 left-turning trucks observed at the intersection during survey, 115 trucks (59 %) made the left-turns by first stopping at the median opening. The other half made the turn from a stop position at the minor roadway.

6.7.6 Queueing Incidents

There were two major queue formation incidents on the eastbound lanes observed during the 3 day survey period. In both cases, two trucks turning in succession forced main highway traffic to a stop, thus resulting in the formation of queues in both lanes. The queue lengths averaged six and seven vehicles in both lanes. Observed cases of vehicles on the main highway slowing down or changing lanes to permit merging trucks onto the highway were also noticed. Traffic queues were not formed in these instances but some degree of congestion occurred at the intersection, resulting in other related incidents.

6.7.7 Lane Changing Along Survey Section

A lane change is accomplished when a vehicle travelling in one lane, shifts lane for an acceptable gap or lag opportunity in an adjacent destination lane. Gaps may either be rejected or accepted based on the operational characteristics of vehicles in the adjacent lanes, such as speed and relative position of other vehicles. The gap acceptance characteristics of a truck attempting a lane change also plays a major role.

Lane changing pattern along the 4 km stretch of highway was obtained by analyzing the traffic data collected on individual lanes at the successive survey posts.

The results from the 3 days data count along the highway is illustrated in Figures 6.4(a-c). These diagrams represent the lane changing and lane choice pattern of trucks along the 4 km highway section.

The band widths show the proportion use of the outside and inside lanes between points. The natural inclination for trucks is to change lanes into the outside lane with traversed distance.

With travelled distance, left-turned trucks attain the speed of highway traffic and can therefore change lanes with much ease. Also with distance, slowed vehicles behind a slow moving truck tend to disperse onto the adjacent lanes, thus creating acceptable gap situation for a truck to change lanes as desired.

6.7.8 Truck Lane Distribution

Lane distribution of surveyed trucks across the highway is considered here on two separate sections of the highway. The first section considered is the distribution in the vicinity of the intersection up to the 200 m post. This distribution is shown in Table 6.2 with the percent of lane use, including shoulders, by trucks within the 200 meters distance from station 0.0 km. Distribution pattern within the section is highly unstable which is reflected by the lane use versus through traffic flow rate plots in Fig 6.2.

The distribution shows that there is an equal proportion of trucks (40 %) within the outside and acceleration lanes. Outside lane trucks were mostly main highway trucks whilst trucks using the acceleration lane were left-turning trucks.

The distribution of trucks on the 4 km section of highway section is analyzed with the assumption that truck lane choice and lane changing maneuvers had been stabilized by the 4 km post.

The overall analysis resulted in a distribution of 83 % of trucks in the outside lane at the 4 km post. This shows that more trucks change lanes into the outside lane with traversed distance. This distribution includes through trucks surveyed at the intersection. If the proportion of through trucks is not considered in the analysis, about 67 percent of left-turn trucks from highway 794 would be considered to have changed lane onto the outside lane by the 4.0 km post.

6.8. Conclusions

The following conclusions can be drawn from the survey on the lane choice of left-turn trucks at the unsignalized intersection studied.

1. The lane selected by a left-turn truck whilst merging into the through multilane highway is found to depend on the flow rate and speed of through traffic.

2. Through vehicles were found to reduce speed or change lanes while approaching the intersection. This is an influencing factor of the left-turning trucks.

3 There were recorded instances of short term queue formation of the through traffic when long trucks or two consecutive trucks made left turns.

4. Incidents, such as the use of inside or outside shoulders by merging trucks were observed to take place with high flow rates on the highway.

5. Gap acceptance or rejection by a left-turning truck depended on the through traffic flow rate.

6. The tendency for heavy vehicles to travel on the outside right lane is confirmed by the high proportion of trucks which were surveyed in the outside lane, 4 km downstream of the intersection.

These findings can be applied to the economic design of highway pavements in the vicinity of intersections. Within the vicinity of intersections with high truck turning movements, the heaviest travelled truck lane could be the inside lane. In such situations, the inside lane should be considered as the controlling design lane and lane distribution factor applications should be based on this lane.

Incidents of shoulder use at intersections by heavy trucks also calls for the adequate design of highway shoulders. These should be designed wide and strong enough to accommodate shoulder encroachments of turning truck traffic.

Table 6.1

Lane Selection by Left-turn Trucks versus Through Traffic Flow Rate at Intersection

Flow rate (2 lanes) (vph)	Flow per Lane (vph)	Total # and % Trks		Accln* lane		Inner lane		Outer* Lane	
0-500	0-250	9	100%	-	-	5	55%	4	45%
500-1000	250-500	2	100%	-	-	-	-	2	100%
1000-1500	500-750	12	100%	1	8%	4	33%	7	59%
1500-2000	750-1000	9	100%	-	-	5	55%	4	45%
2000-2500	1000-1250	8	100%	-	-	6	75%	2	25%
2500-3000	1250-1500	4	100%	1	25%	3	75%	-	-
3000-3500	1500-1750	4	100%	2	50%	2	50%	-	-
3500-4000	1750-2000	1	100%	1	100%	-	-	-	-
4000 >	2000>	2	100%	2	100%	-	-	-	-

* - Values for acceleration and Outside lanes include use of inner and outer shoulders

Table 6.2

Distribution of left-turn trucks between Highway Section

0.0 km - 0.20 km

Lane use	Number of Trucks	Percent Trucks	# Cars
Inner shoulder	7	5.7	2
Accln Lane	49	39.8	162
Inner (Median) lane	14	11.4	577
Outside lane *	48	39.0	706
Outer shoulder	5	4.1	

* Outside Lane trucks include both left-turn and through trucks

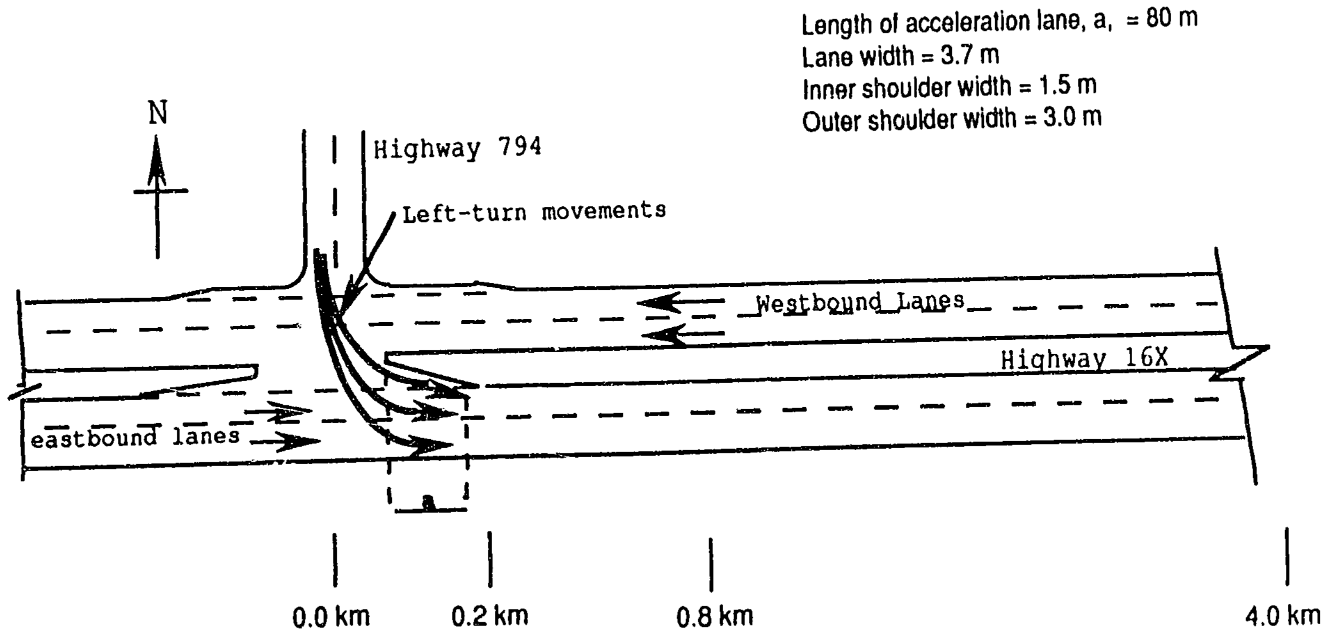


Figure 6.1. Condition Diagram at Surveyed Intersection

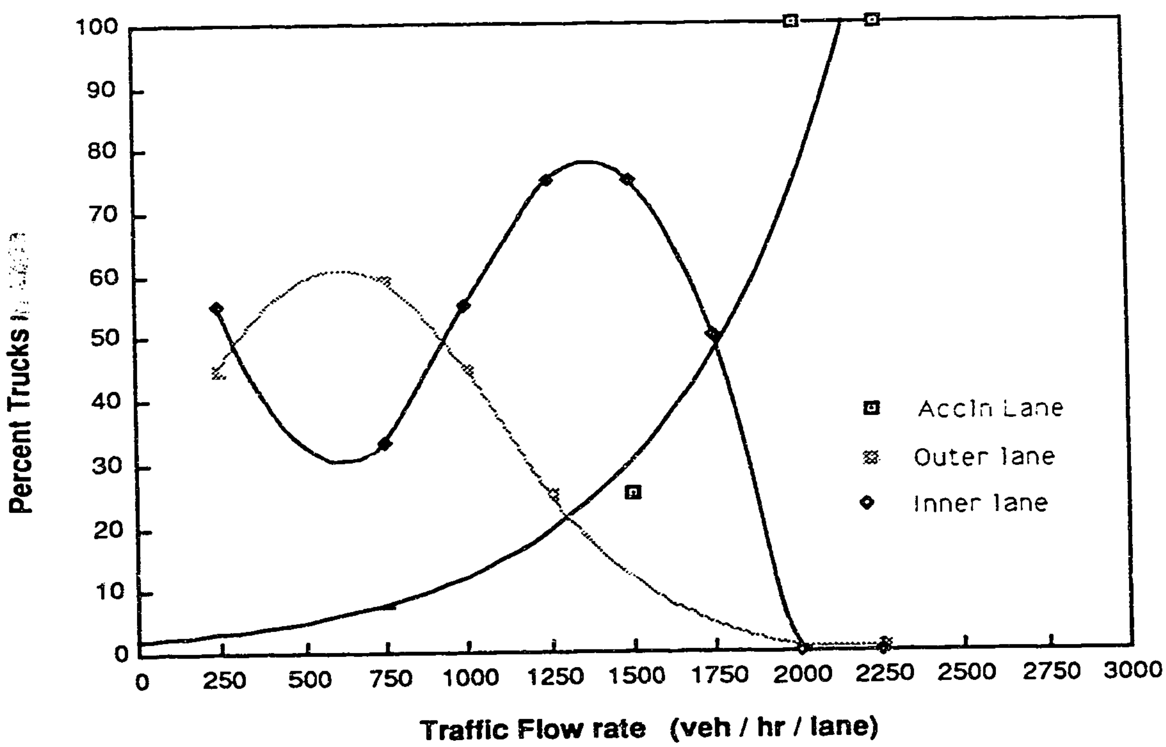
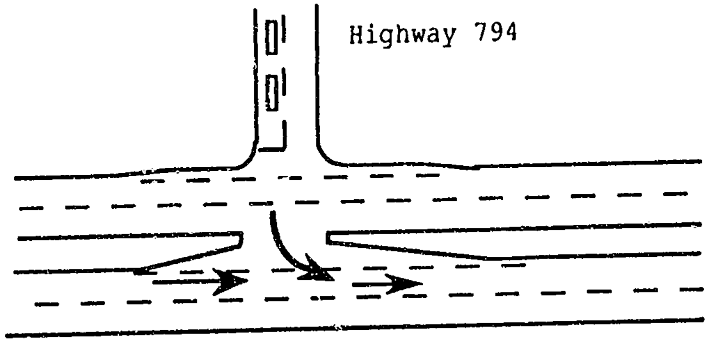
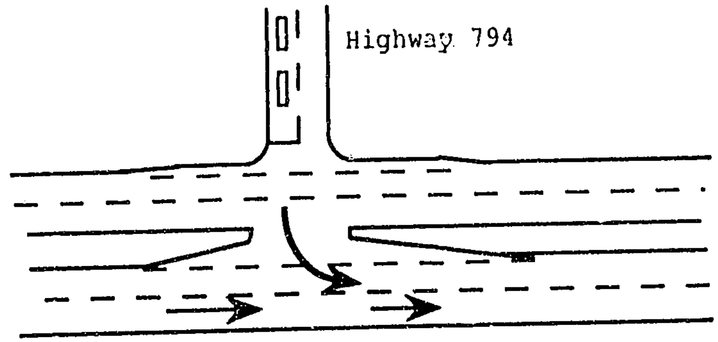


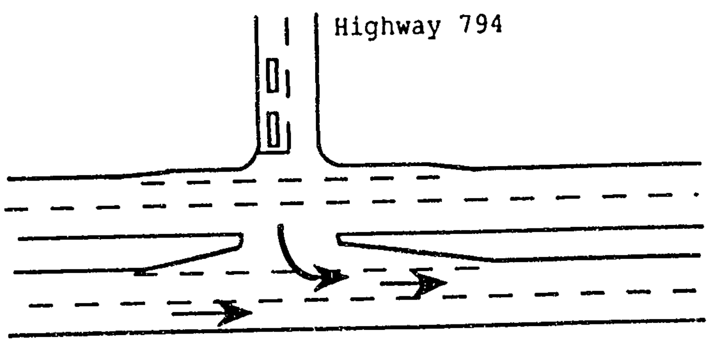
Figure 6.2 Lane Choice by Left-turn Trucks at intersection versus through traffic flow rate



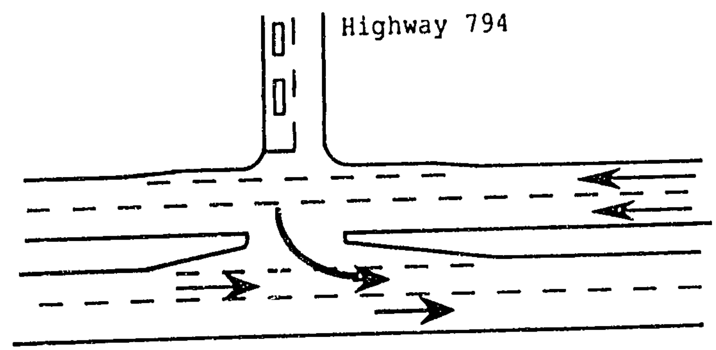
(a) Inside lead, inside lag



(b) Outside lead, outside lag



(c) Inside lead, Outside lag



(d) Outside lead, inside lag

Figure 6.3 Acceptable Gap types in traffic stream

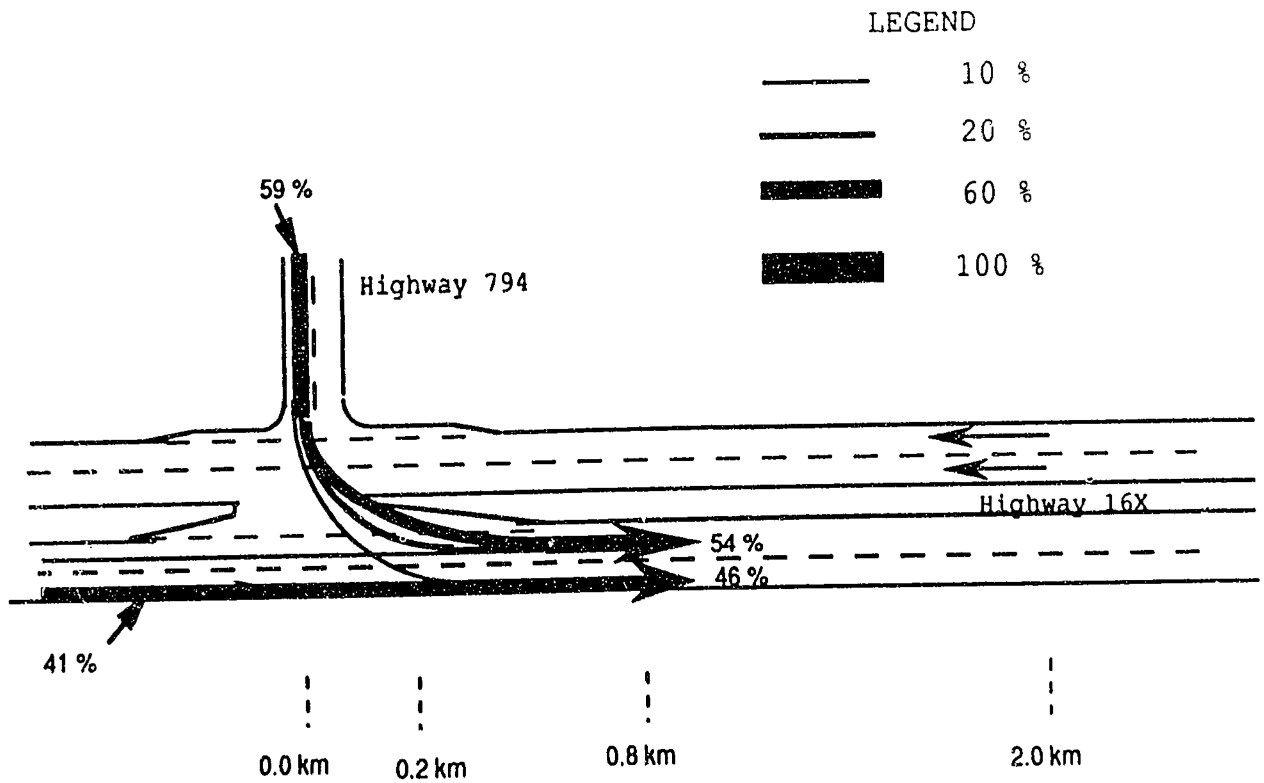


Figure 6.4a. Distribution pattern of left turning trucks along highway section (Survey # 1)

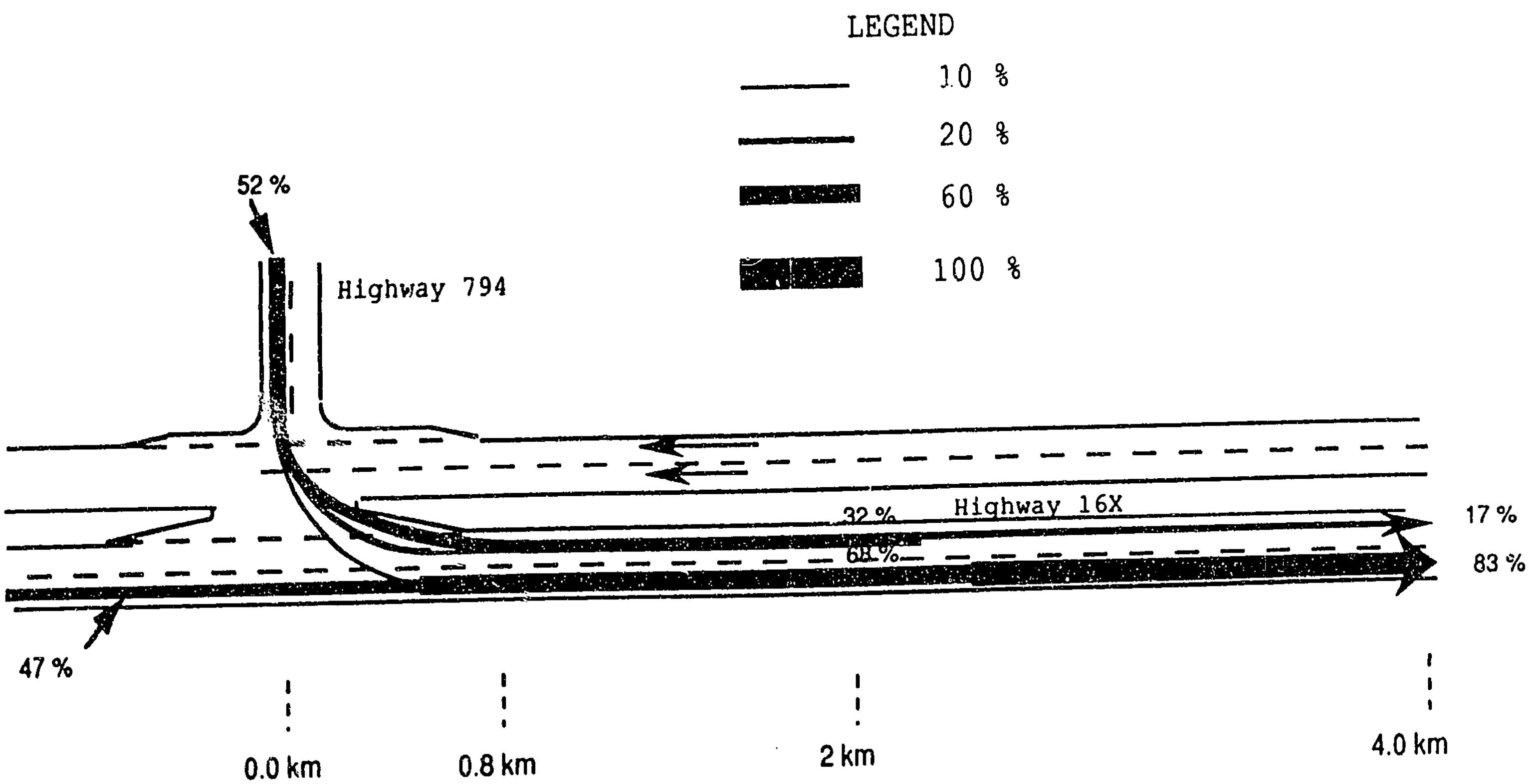


Figure 6.4b. Distribution pattern of left turning trucks along highway section (Survey # 2)

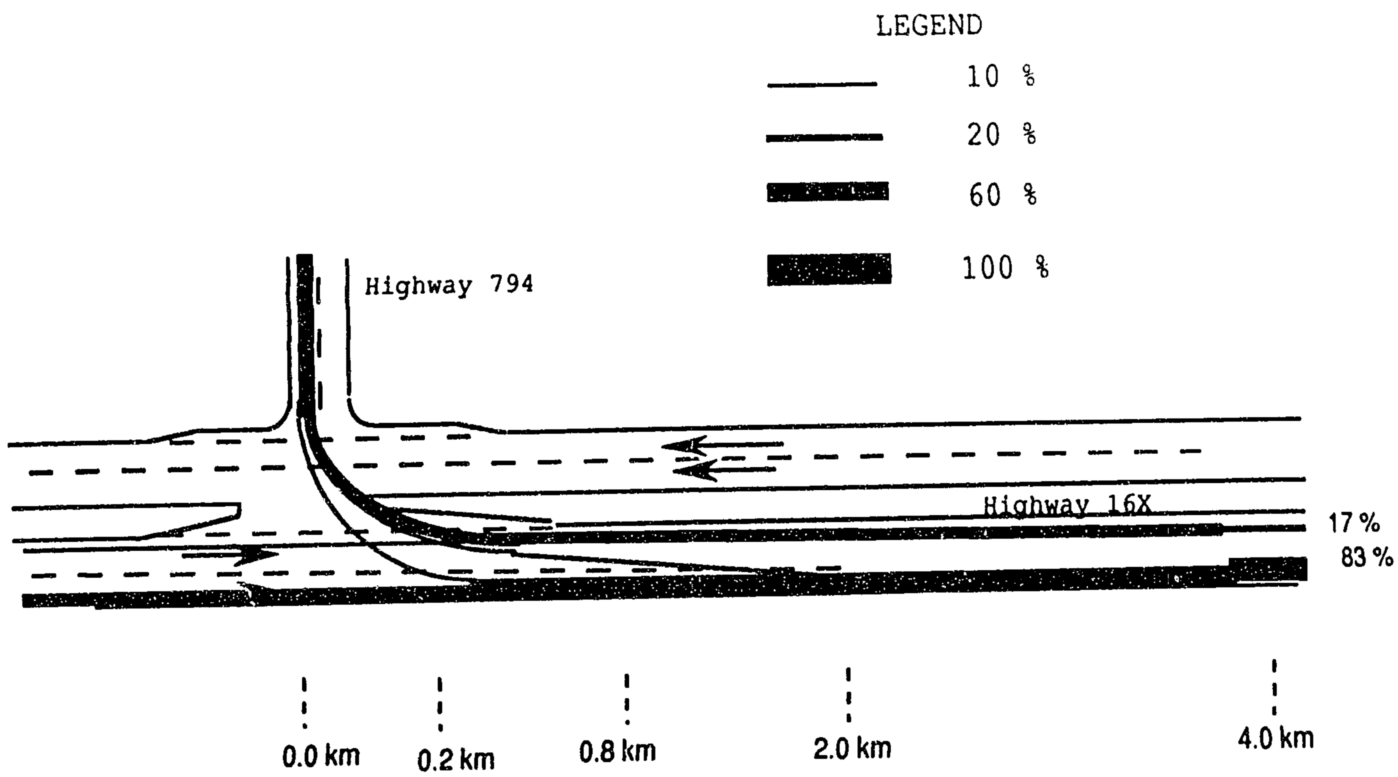


Figure 6.4c. Band diagram showing the distribution pattern of left turning trucks along highway section

CHAPTER 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1. Summary

This study covered the subject of the Truck Lane and Axle Load Distribution on multilane rural highways in the province of Alberta. Specifically, data from the WIM scale at Leduc was used for determining the traffic loading distribution on the pavement structure for a typical primary highway in the province. Cumulative ESALs generated by trucks during two separate years of continuous data collection from this scale also served as the basis for translating the annual accumulated loadings into equivalent pavement thicknesses. Both the Asphalt Institute (AI) and Portland Cement Association (PCA) design approaches were employed in the flexible and rigid pavement thickness analysis.

Pre- and Post-1988 truck loading data from the WIM site enabled an assessment of the changes in truck number, axle load, lane use and axle configuration in the province after the 1988 RTAC weight limit recommendations.

In addition, an intersection study of the lane choice patterns of left-turning trucks onto a multilane highway as well as lane changing characteristics and traffic conflict events such as weaving, stopping and queuing by main stream traffic were investigated.

These studies were conducted against a background of literature review on truck traffic influence on the highway system. This review dealt with a wide range of truck related topics including past studies on lane distribution factors, the ESAL concept, the use of weigh-in-motion scales for collecting traffic data and axle load information and a review of RTAC truck weight and dimension limits. The influence of trucks on highway traffic and intersection operations were also reviewed.

The literature reviewed and the WIM data analyzed, presented the opportunity to draw valid conclusions on loading and Lane Distribution Factors (LDF) at the particular highway section in Alberta and to make recommendations on future research work required to enhance the assessment of truck loading on the highway lanes.

7.2. Conclusions

Based on the findings of this study and the review of published literature, the following conclusions and results can be drawn on the truck lane use and loading distribution on multilane rural highways in the province.

1. Increases in average truck axle weights, changes in truck traffic composition and increases in truck volumes have together contributed to significant increase in total ESALs after the RTAC weight regulations in 1988. The overall

increase in average gross vehicle weights soon after the weight changes translates as 1.8 tonnes.

2. Seasonal variations in generated ESALs relate closely to the number of trucks on the highway. High ESALs are generated in the spring and summer months. Truck volumes and loadings are at their lowest during the winter. The observed increase in truck volumes translates to about 32 percent growth between the two analyzed periods.

3. Most ESALs on the highway are generated by the heavy truck categories. These truck types represent 64 percent of all trucks but generate 89 percent of the daily ESALs.

In general over 90 percent of truck traffic use the outside design lane generating about 85 percent of the one directional total ESALs.

4. ESALs per pass increased within the analyzed period. The most significant increase were in semitrailer and combination truck units. ESAL factors for all truck types using the inside lane showed a consistently higher values than those in the outside lane. On the average, a factor of 2.04 was determined for truck loading in the inside lane while a factor of 1.41 was established for the outside lane traffic. A correlation coefficient of 0.905 and 0.605 were analyzed for the outside lane and inside lane truck volumes versus daily ESALs plots respectively.

Although an explanation for the use of the inside lane by heavily loaded trucks can not be readily given, a policy to enforce weight limits on trucks could be justified by sampling trucks in the inside lanes.

5. Overloaded trucks represented 3.4 percent of all trucks and contributed about 18 percent of generated ESALs on the highway in 1989. When one considers axle groups, most overloads were on tridem axle groups.

6. The cumulative ESAL generated during the eight months (April-December) in 1989 was about 1.8 times the cumulative ESALs of 1986. Average ESAL Factor increased from 1.05 in 1986 to 1.4 in 1989.

7. The predominant truck type is the five-axle semi-trailer truck (Type 9). This truck type contributes over half of the total accumulated ESALs.

8. Overloaded trucks generated about 18 percent of total daily ESALs. More combination trucks of the six-axle and seven axle groups are found to be overloaded. When one considers overloading in axle groups, a higher percentage of tridem axles exceed the maximum allowable limits.

9. The RTAC recommendations on weight limits will result in a 30 mm additional pavement thickness requirement and an increased rate of highway rehabilitation. Eliminating trucks operating over the set weight limits will save 10 mm

of full depth asphalt thickness. Similar conclusions can be drawn for the analysis of rigid pavement thickness.

From the preceding discussions and conclusions, it is clear that the lane distribution factor on the highway is on the higher end of the distribution recommended by most agencies. Also the RTAC changes had an immediate impact on truck activities in the province. The eventual adoption and complete change to use the recommended RTAC standard trucks could result in variations in the above stated conclusions.

Projections of loadings before and after the weight changes for 20 years periods reveal that an extra full depth asphalt pavement depth of 30 mm may be required to support the increases in loading.

The following conclusions can be drawn from the survey on the lane choice of left-turn trucks at the unsignalized intersection studied.

1. The lane selected by a left-turn truck when merging into the through multilane highway is found to depend on the flow rate and speed of through traffic.

2. Through vehicles were found to reduce their speed or changed lanes while approaching the intersection.

3 Short term moving queues of through traffic were recorded when long trucks or two consecutive trucks made turns.

4. Incidents such as inside shoulder or outside shoulder use by merging left-turn trucks were observed to take place with high flow rates on the highway. Gap acceptance by a truck depends on the rate of flow on adjacent lanes.

5. The inclination of truck drivers to select the outside right lane for travel is confirmed by the high proportion of truck distribution 4 km downstream of the intersection.

Basically for a flow of over 3000 veh/hr (one directional flow of 2 lanes), truck drivers either reject and wait for an acceptable gap or utilize the inner lane or the inner shoulder for turning manoeuvres.

The choice of lanes within the vicinity of the studied intersection does not follow a consistent lane selection pattern. Drivers are much influenced by the flow conditions of through traffic at the intersection.

The findings can be applied to the economic design of highway pavements in the vicinity of intersections. At intersections with high truck turning movements, the heaviest traveled truck lane would be the inside lane. This lane should be considered as the controlling design lane. Applied lane distribution factors and ESAL generation should be based on the proportion of inside lane use by trucks.

Highway pavement shoulders at intersections should also be designed wide and thick enough to accommodate the incidental use by turning truck traffics.

7.3. Recommendations

It is believed that the RTAC weight and dimensions limits proposed in 1988 will have its full impact when the provinces change, and start adopting, the proposed standard trucks. It may require some time, maybe years, before the present truck fleets in the system are totally replaced with the RTAC standard truck types for an accurate loading assessment to be made. It is therefore recommended that further research be conducted on future available data from the WIM scale to assess the long term impact of the weight changes.

One major limitation of the research is the unavailability of continuous truck weight data on other primary highways in the province. Such data could permit a much accurate general conclusion to be made on truck loading on Alberta's primary highways. It is recommended that future analysis take into consideration primary highways with no established WIM scales. This could be based on the finding that a survey on representative five axle trucks on the highway could be factored up to give ESAL values within reasonable accuracy for pavement design purposes.

It is recommended that weight enforcement action on heavy trucks be carried out on the trucks using the inside lane of the highway.

The economic evaluation of trucking before and after weight changes is recommended in future studies to assess the weight increase impacts in terms of user benefits and costs.

Bibliography

Agarwal A.C., 1978. *"Vehicle Weight Regulat- across Canada: A Technical Review with Respe to the Capacity of Highway Systems"*, Ontario Ministry of Transportation and Communications.

Alberta Transportation and Utilities, 1989. *"Traffic Volume, and Vehicle Class Statistics"*, Edmonton. Alberta.

Alberta Transportation and Utilities, 1989. *"Traffic, Travel, and ESAL Statistics for Primary Highways and Secondary Roads"*, Edmonton. Alberta.

American Association of State Highway and Transportation Officials, (AASHTO), 1986. *"AASHTO Guide for Design of Pavement Structures, 1986"*, Washington, D.C.

American Association of State Highway Transportation Officials (AASHTO), 1983. *"Manual for Maintenance Inspection of Bridges"*, Washington, D.C.

American Association of State Highway Transportation Officials (AASHTO), 1984. *"A policy on the Geometric Design of Highways and streets"*, Washington, D.C.

American Society of Civil Engineers, 1988. *"Accommodation of Trucks on the Highway: Safety in Design"*, Proceeding of the Symposium organized by the Committee on Geometric Design of the Highway Division of the ASCE. Nashville,Tennessee

Asphalt Institute, 1981. *"Thickness Design - Asphalt Pavements for Highways and Streets"*, College Park, Md.

Backlund R.E. and J.E. Gruver, 1990. *"Heavy Trucks on the Highways: An Important Pavement Issue"*, Transportation Research Board. 69th Annual Meeting. Washington, D.C.

Bergan A.T., G.A. Sparks, and G. Dyck, 1978. *"Weighing Vehicles in Motion"*, Transportation Research Record 667, TRB, National Research Council, Washington, D.C. pp.28-34.

Bergan John P. and Ralph Smith, 1975. *"Evaluation of a Dynamic Vehicle Weighing System"*, Paper presented to Institute of Transportation Engineers, Maritime region.

Canro nsportation Research Corporation, 1986. "*Vehicle ights and Dimension Study: Technical Steering Committee Report*", Roads and Transportation Association of Canada, Ottawa.

Cepas A. S., 1984. "*Annual Summary for the 156 Street WIM Site*", The City of Edmonton Materials and Testing Engineering Department. Edmonton, Alberta.

Chong G. J., G. M. Scott and W.A. Phang, 1972. "*The Viatec Axle-Weight Analyzer and Analysis of Axle-load Data*", Department of Transportation and Communication of Ontario Report No. IR47.

Christison J. T. and I. V. Krumins, 1983. "*Truck Traffic Load Demands on Alberta Highways; 1970-1980*", Alberta Research Council. Edmonton. Alberta.

Clark M. F., 1969. "*Present Method of Pavement Design in Saskatchewan*", Western Association of Canadian Highway Officials, Edmonton.

Cunagin W. D, 1987. "*Lane Distribution Factors for Design*", Texas Transportation Institute, Cooperative Research Program.

Cunagin W. D. and E.C. Chang, 1982. "*Effects of Trucks on Freeway Vehicle Headways Under Off-peak Flow Conditions*", Transportation Research Record 869, p.54-59

Darter M. I., Becker J. M., Snyder M. B., and Smith, R. E., 1985. "*Portland Cement Concrete Pavement Evaluation System (COPES)*", Report 277, National Cooperative Highway Research Program, Transportation Research Board.

DeCabooter P. H., and C.E. Solberg, 1989. "*Geometric Considerations Relating to Long Truck Operations on the Designated Highway System in Urban Areas*", In Transportation Research Record No , National Research Council. Washington, D.C.

Fredericks T.W., 1989. "*The Benefits of 62.5 tonnes, 25 meter B-trains in Alberta*", Paper presented at the 2nd international symposium on heavy vehicle weights and dimensions. RTAC.

Garcia-Diaz A., Riggins M., and Liu S.J., 1984. "*Development of Performance Equations and Survivor Curves for Flexible Pavements*", Texas Transportation Institute Research Report 284-5, Texas A&M University.

Haas R. and W. R. Hudson, 1978. "*Pavement Management Systems*", Mcgraw-Hill Book Co., New York.

Highway Research Board (HRB), 1962. "*The AASHO Road Test*", Special Report 73. Proceedings of a conference, St. Louis, Missouri. HRB, National Research Council, Washington, D.C., 1962.

Highway Research Board (HRB), 1962. "*The AASHO Road Test, Report 5: Pavement Research*", Special Report 61E. National Research Council, Washington, D.C.

Lowe J. B, and Bergan A.T., 1983. "*Installation and Operation of Weigh-in-Motion Data and Sorter Scales in Alberta*", Alberta Transportation, Research and Development Branch. Edmonton. Alberta.

McCasland, W. R, and Stokes, R. W, "*Truck Operations and Regulations on Urban Freeways*", Texas State Department of Highways and Public Transportation

Moshe Levin, 1976. "*Freeway Lane-Changing Process: A Microscopic Approach*", Transportation Research Record 596, p. 30-32

Neal A.Irwin., Barton, R.A., 1989. "*Economics of Truck Sizes and Weights in Canada*", Paper presented at the 2nd international Symposium on Heavy Weights and Dimensions.

Nix F. P., 1988. "*Impact of RTAC Regulations on Trucking in Canada*", A paper prepared for Transport Canada for presentation to TRB, Ottawa, Ontario.

Nix F.P.,Clayton, A.M., Bisson, B.G., 1987. "*Study of Vehicle Weight and Dimension Regulations and Canada's Trucking Industry: The Regulations*", Transportation Development Centre, Montreal.

Noblitt Jack L., 1959. "*A study of Gaps Associated with a Left-Turning Truck*", Thesis Manuscript, Yale Univ.

Portland Cement Association (PCA), 1984. "*Thickness Design for Concrete Highway and Street Pavements*", Skokie, Ill.

Portland Cement Association (PCA), 1985. "*PCAPAV, Thickness Design of Highway and Street Pavements*", Version 1.1. Paving and Transportation Department, Skokie, Ill

Rhodes A.H., 1983. *"Road Damage and the Vehicle"*, Endeavour, New series, Vol. 7, no.1, University of Newcastle Upon Tyne.

Rhodes A.H., 1990. *"Reducing Whole Life Costs"*, Highways and Transportation, Vol 37. no 11, p.53-54, University of Newcastle Upon Tyne.

Rorbech Jens, 1976. *"Multilane Traffic Flow Process: Evaluation of Queuing and Lane-Cahnging Patterns"*, Transportation Research Record 596, p. 22-29.

RTAC, 1981. *"Dynamic Weigh-in-motion Scales"*, Ottawa, Canada.

RTAC, 1986. *"Manual of Geometric Design Standards for Canada Roads"*, Ottawa. Canada.

RTAC, 1987. *"Vehicle Weights and Dimensions Study; Recommended Regulatory Principles for Interprovincial Heavy Vehicle Weights and Dimensions"*, Implementation Planning Sub-committee. Ottawa. Canada.

RTAC, 1988. *"Memorandum of Understanding on Interprovincial Vehicle Weights and Dimensions"*, Council of Ministers of Transportation and Highway Safety. Ottawa. Canada.

Shields B.P., 1974. *"Truck Factors 1970-1972"*, Alberta Research Council, Highway and River Engineering Division.

Shields B.P., 1976. *"An Analysis of Truck Axle Weights in Relation to Increased Load Allowances"*, Alberta Research Council. Edmonton. Alberta.

Shields B.P. and H.L. Wagner, 1978. *"Truck Weight Surveys, Alberta; 1970-1977"*, Alberta Research Council. Edmonton. Alberta.

Solberg, Per, J.C. Oppenlander, 1965. *"Lag and Gap Acceptances at Stop-Controlled Intersection"*, Highway Research Record 118, p. 73-97.

Statistics Canada, 1987. *"Trucking in Canada 1985"*

Texas Highway Department, 1984. *"Flexible Pavement Designer's Manual, Pavement Design System Part I"*, Highway Division, THD.

Texas Transportation Institute, 1987. *"Development of Traffic Data Collection Standards: Pavement Management Study"*.

Thygesen, M.B.A., Khalil, S.M., Bedi, I.S., Keown, L.L., 1989. *"Alberta's Weight Enforcement Program and its Impact on Pavement Costs"*, Proceedings of Second International Symposium on Heavy Vehicle Weights; Roads and Transportation Association of Canada.

Transportation Research Board (TRB), 1984. *"Distribution of Wheel Loads on Highway Bridges"*, Synthesis of Highway Practice No 111. National Cooperative Highway Research Program (NCHRP). Washington, D.C.

Transportation Research Board (TRB), 1985. *"Highway Capacity Manual"*, Special Report 209, National Research Council. Washington, D.C.

Transportation Research Board (TRB), 1986. *"Twin Trailer Trucks: Effects on Highways and Highway Safety"*, Special Report 211, National Research Council. Washington, D.C.

Transportation Research Board (TRB), 1986. *"The Operation of Larger Trucks on Roads with restrictive Geometry"*, National Technical information Service. Washington, D.C.

Transportation Research Board (TRB), 1986. *"Use of Weigh in Motion Systems for Data Collection and Enforcement"*, NCHRP, Synthesis of Highway Practice No 124. Washington, D.C.

Transportation Research Board (TRB), 1989. *"Providing Access For Large Trucks"* Special Report 22, National Research Council. Washington D.C.

Transportation Research Board (TRB), 1990. *"Truck Weight Limits, Issues and Options"* Special Report 225, National Research Council. Washington, D.C.

Transportation Research Board (TRB), 1987. *"Effects of Permit and Illegal Overloads on Pavements"*, National Cooperative Highway Research Program (NCHRP), Synthesis of Highway Practice 131. Washington. D.C.

U.S. Secretary of Commerce, 1964. *"Maximum Desirable Dimensions and Weights of Vehicles Operated on the Federal-Aid Systems"*, 88th congress, 2nd Session, House Document No. 354.

U.S. Department of Transportation, 1981. *"National Truck Characteristic Report, 1975-1979"*, Federal Highway Administration, Washington, D.C.

Wagner, F.A., Jr., 1965. "*An Evaluation of Fundamental Driver Decisions and Reactions at an Intersection*", Highway Research Record 118, p. 68-84.

Wardrop J. G., 1952. "*Some Theoretical Aspects of Road Traffic Research*", Proceedings, Institute of Civil Engineers. Pt. II, 1, 325-362.

Yoder E. J.and Witzczak M.W.,1975. "*Principles of Pavement Design*", Wiley 1975

APPENDIX A

Sample Output from WIM scale

```
stats

POWER OFF
    FROM                 TO
Fri Feb  3 14:12   Thu Feb 16 16:30
Mon Mar 20 14:54   Mon Mar 20 14:58
Mon Mar 20 15:00   Mon Mar 20 15:10
Wed Apr 26 22:00   Wed Apr 26 23:10

System Counters from Tuesday May 1 09:16 to Monday May 15 13:04

Remote processor 1 is operating.
          15 bad characters.       0 bad packets.      96 bad packet contents.
Lane 1:
  Number    %    Description
  339330   83.4   Weighec
     193    0.0   Loop A only
     574    0.1   Loop B only
      11    0.0   Bad entry (loop B triggered first)
      54    0.0   Too slow
       8    0.0   Too fast
   40711   10.0   Hit offscale detector
       1    0.0   Too many axles
   26175    6.4   Missed scale
  407057  100.0   Total
Lane 2:
  Number    %    Description
  105068   68.7   Weighec
     377    0.2   Loop A only
     155    0.1   Loop B only
       9    0.0   Bad entry (loop B triggered first)
      90    0.1   Too slow
       3    0.0   Too fast
   37797   24.7   Hit offscale detector
       0    0.0   Too many axles
    9363    6.1   Missed scale
  152862  100.0   Total

Storage Device Status:
     0 Data Transfer Errors
     0 Last Error
```

scl>tables

Number of Vehicles and 18-K ESAL by Day of Week (Lane 1)

Alberta Transportation -- Leduc Scale Sit
From: Monday May 1 00:00 To: Monday May 8 00:00

Type	Monday #	Monday 18-K	Tuesday #	Tuesday 18-K	Wednesday #	Wednesday 18-K	Thursday #	Thursday 18-K	Friday #	Friday 18-K	Saturday #	Saturday 18-K	Sunday #	Sunday 18-K	Total #	Average 18-K	%	% of Trucks
1	2811	0.000	2557	0.000	2542	0.000	2685	0.000	3761	0.000	3505	0.000	4886	0.000	22747	0.000	81.5	0.0
2	76	0.000	82	0.000	81	0.000	68	0.000	104	0.000	99	0.000	137	0.000	647	0.000	2.3	0.0
3	109	0.[illegible]86	112	0.217	131	0.250	118	0.213	137	0.244	96	0.248	106	0.124	809	0.227	2.9	17.9
4	32	0.967	37	1.177	41	1.120	52	1.392	43	1.191	35	1.132	23	0.668	263	1.137	0.9	5.8
5	9	0.585	8	0.366	12	0.390	15	0.413	14	0.266	9	0.326	11	0.208	78	0.359	0.3	1.7
6	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.0	0.0
7	38	0.485	30	0.393	32	0.540	28	0.755	48	0.521	15	0.145	26	0.439	217	0.494	0.8	4.8
8	8	0.647	9	1.405	13	0.848	9	0.539	7	0.375	5	0.085	7	0.529	58	0.697	0.2	1.3
9	294	1.725	264	1.640	293	1.860	311	1.765	272	1.715	158	1.937	126	1.555	1718	1.748	6.2	38.0
10	1	0.372	0	0.000	0	0.000	0	0.000	3	0.746	0	0.000	0	0.000	4	0.653	0.0	0.1
11	10	1.666	12	1.387	6	1.016	8	1.696	10	1.055	3	2.926	1	2.929	50	1.504	0.2	1.1
12	5	3.785	3	1.975	8	3.500	3	2.758	6	4.105	8	3.133	4	4.373	37	3.468	0.1	0.8
13	11	0.708	12	1.095	9	0.632	6	0.974	9	1.256	10	1.262	3	1.466	60	1.013	0.2	1.3
14	53	2.674	59	2.991	70	3.735	49	2.859	58	2.668	36	2.394	26	3.137	351	2.969	1.3	7.8
15	49	2.999	78	2.785	75	2.872	53	2.823	58	2.422	28	2.368	[illegible]	[illegible].074	358	2.713	1.3	7.9
16	1	0.732	2	1.954	2	1.419	1	1.823	1	1.426	0	0.000	0	0.000	7	1.532	0.0	0.2
17	5	0.866	10	1.403	8	0.873	11	1.069	5	1.330	0	0.000	0	0.000	39	1.122	0.1	0.9
18	21	1.866	25	2.371	27	2.007	29	1.775	25	1.915	2	1.693	2	3.373	131	2.001	0.5	2.9
19	46	1.871	65	2.432	49	2.273	66	1.877	48	2.110	31	2.228	32	2.097	337	2.127	1.2	7.5

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Total
Total Trucks Weighed	692	726	776	759	744	436	384	4517
Total Vehicles Weighed	3579	3365	3399	3512	4609	4040	5407	27911
Total 18-K ESAL	1060.792	1192.855	1348.572	1184.885	1083.729	646.514	457.347	6974.692
Total not weighed	657	594	622	651	734	[illegible]	745	4600

Number of Vehicles and 18-K ESAL by Day of Week (Lane 2)

Alberta Transportation -- Leduc Scale Sit
From: Monday May 1 00:00 To: Monday May 8 00:00

Type	Monday #	Monday 18-K	Tuesday #	Tuesday 18-K	Wednesday #	Wednesday 18-K	Thursday #	Thursday 18-K	Friday #	Friday 18-K	Saturday #	Saturday 18-K	Sunday #	Sunday 18-K	Total #	Average 18-K	%	% of Trucks
1	929	0.000	874	0.000	1029	0.000	1011	0.000	1726	0.000	1350	0.000	2095	0.000	9014	0.000	96.3	0.0
2	5	0.000	9	0.000	8	0.000	3	0.000	12	0.000	10	0.000	12	0.000	59	0.000	0.6	0.0
3	11	0.259	7	0.314	17	0.255	16	0.308	18	0.525	12	0.690	15	0.398	96	0.396	1.0	33.6
4	4	1.674	4	1.042	5	0.803	6	0.732	9	1.246	6	1.444	9	0.997	43	1.119	0.5	15.0
5	1	0.035	1	0.028	1	1.965	0	0.000	1	0.014	1	1.914	0	0.000	5	0.791	0.1	1.7
6	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.0	0.0
7	2	3.439	0	0.000	0	0.000	2	0.017	6	0.899	1	0.586	5	0.032	16	0.816	0.2	5.6
8	0	0.000	0	0.000	1	0.510	0	0.000	1	0.081	0	0.000	1	0.029	3	0.207	0.0	1.0
9	15	2.924	16	2.663	8	2.640	8	2.057	17	3.011	3	1.727	5	2.554	72	2.683	0.8	25.2
10	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.0	0.0
11	0	0.000	2	6.058	0	0.000	0	0.000	0	0.000	0	0.000	1	2.748	3	4.955	0.0	1.0
12	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.0	0.0
13	0	0.000	0	0.000	0	0.000	0	0.000	2	1.120	0	0.000	0	0.000	2	1.120	0.0	0.7
14	5	4.2[illegible]1	4	2.469	1	1.150	2	8.657	7	5.078	3	0.723	11	3.163	23	4.360	0.2	8.0
15	3	2.504	4	4.585	0	0.000	2	6.294	2	9.117	0	0.000	0	0.000	11	5.234	0.1	3.8
16	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.0	0.0
17	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.0	0.0
18	2	5.127	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	2	5.127	0.0	0.7
19	1	0.725	1	4.311	3	8.059	3	7.551	1	0.657	1	0.966	0	0.000	10	5.349	0.1	3.5

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Total
Total Trucks Weighed	44	39	36	39	64	27	37	286
Total Vehicles Weighed	978	922	1073	1053	1802	1387	2144	9359
Total 18-K ESAL	100.771	93.634	57.271	78.365	134.013	27.759	43.815	535.629
Total not weighed	429	355	368	347	979	575	988	4041

Number of Vehicles and 18-K ESAL by Day of Week (Lane 1)

Alberta Transportation -- Leduc Scale Sit
From: Monday May 8 00:00 To: Monday May 00:00

Type	Monday #	Monday 18-K	Tuesday #	Tuesday 18-K	Wednesc #	Wednesc 18-	Thursday #	Thursday 18-K	Friday #	Friday 18-K	Saturday #	Saturday 18-K	Sunday #	Sunday 18-K	Total #	Average 18-K	%	% of Trucks
1	2659	0.000	1581	0.000	2613	0.000	2679	0.000	3917	0.000	3714	0.000	5027	0.000	22190	0.000	80.9	0.0
2	95	0.000	63	0.000	96	0.000	91	0.000	134	0.000	117	0.000	151	0.000	747	0.000	2.7	0.0
3	116	0.239	71	0.210	125	0.213	130	0.245	125	0.153	75	0.213	122	0.132	764	0.199	2.8	17.0
4	41	1.046	29	0.817	48	1.300	47	0.993	31	1.149	25	0.821	27	0.847	248	1.027	0.9	5.5
5	8	0.577	7	0.257	10	0.284	18	0.626	12	0.702	11	0.325	12	0.120	78	0.435	0.3	1.7
6	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.0	0.0
7	32	0.709	19	0.408	31	0.355	23	0.576	33	0.362	15	0.492	18	0.230	171	0.457	0.6	3.8
8	10	0.534	11	0.482	7	0.797	12	0.718	12	0.229	5	0.879	8	0.441	65	0.546	0.2	1.4
9	272	1.851	230	1.745	327	1.908	306	1.790	293	1.745	136	1.893	138	1.896	1702	1.825	6.2	37.9
10	1	2.911	0	0.000	2	0.400	0	0.000	1	0.536	0	0.000	0	0.000	4	1.062	0.0	0.1
11	10	1.614	9	2.322	8	0.795	7	2.827	5	0.735	7	1.449	3	1.350	49	1.654	0.2	1.1
12	7	3.115	3	3.692	3	2.859	11	4.999	8	3.696	4	4.188	5	2.031	41	3.730	0.1	0.9
13	7	0.772	6	0.837	13	1.079	11	2.189	9	1.058	5	1.140	4	0.481	55	1.194	0.2	1.2
14	66	2.524	49	3.094	58	2.478	66	3.148	80	2.526	32	2.099	25	2.393	376	2.656	1.4	8.4
15	58	2.296	51	2.631	76	2.136	80	2.604	62	2.245	44	2.464	20	2.725	391	2.404	1.4	8.7
16	2	1.211	3	1.182	1	0.809	2	0.636	1	0.987	0	0.000	0	0.000	9	1.004	0.0	0.2
17	7	0.771	5	1.352	10	0.801	11	1.351	7	0.939	0	0.000	0	0.000	40	1.040	0.1	0.9
18	25	2.055	18	2.098	34	2.121	30	2.672	21	2.001	0	0.000	5	1.722	133	2.196	0.5	3.0
19	63	2.239	45	1.951	68	2.384	57	1.834	60	2.631	42	1.970	24	2.812	359	2.238	1.3	8.0

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Total
Total Trucks Weighed	725	556	821	811	760	401	411	4485
Total Vehicles Weighed	3479	2200	3530	3581	4811	4232	5589	27422
Total 18-K ESAL	1153.151	913.524	1311.324	1374.993	1181.200	600.213	516.305	7050.711
Total not weighed	720	1687	604	677	899	674	878	6139

Number of Vehicles and 18-K ESAL by Day of Week (Lane 2)

Alberta Transportation -- Leduc Scale Sit
From: Monday May 8 00:00 To: Monday May 15 00:00

Type	Monday #	Monday 18-K	Tuesday #	Tuesday 18-K	Wednesday #	Wednesday 18-K	Thursday #	Thursday 18-K	Friday #	Friday 18-K	Saturday #	Saturday 18-K	Sunday #	Sunday 18-K	Total #	Average 18-K	%	% of Trucks
1	946	0.000	815	0.000	994	0.000	1095	0.000	1832	0.000	1226	0.000	2380	0.000	9288	0.000	96.0	0.0
2	8	0.000	7	0.000	3	0.000	9	0.000	6	0.000	4	0.000	9	0.000	46	0.000	0.5	0.0
3	30	0.500	18	0.525	14	0.614	22	1.035	14	0.154	9	0.715	14	0.661	121	0.609	1.3	35.5
4	6	1.340	5	0.968	6	0.927	3	0.385	9	1.070	8	1.093	6	1.505	43	1.093	0.4	12.6
5	2	0.036	0	0.000	1	0.880	0	0.000	0	0.000	1	0.016	0	0.000	4	0.242	0.0	1.2
6	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.0	0.0
7	1	0.732	117.558		1	0.035	1	5.277	0	0.000	0	0.000	5	0.267	9	2.770	0.1	2.6
8	0	0.000	0	0.000	1	3.943	0	0.000	0	0.000	0	0.000	0	0.000	1	3.943	0.0	0.3
9	29	3.532	14	2.707	10	5.085	15	3.801	16	5.341	4	6.266	7	2.504	95	3.960	1.0	27.9
10	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.0	0.0
11	0	0.000	1	4.467	0	0.000	1	0.831	0	0.000	0	0.000	0	0.000	[illegible]	2.649	0.0	0.6
12	0	0.000	0	0.000	1	1.253	112.268		0	0.000	1	1.009	0	0.000	3	4.843	0.0	0.9
13	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	1	1.576	0	0.000	1	1.576	0.0	0.3
14	4	2.037	2	3.243	4	6.755	3	1.925	5	2.532	5	4.641	1	1.018	24	3.513	0.2	7.0
15	8	7.533	1	6.999	0	0.000	2	4.616	3	3.712	1	8.572	0	0.000	15	6.413	0.2	4.4
16	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.0	0.0
17	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0.0	0.0
18	0	0.000	120.650		1	5.686	0	0.000	1	2.382	0	0.000	0	0.000	3	9.573	0.0	0.9
19	4	3.605	4	3.319	3	0.905	4	4.982	2	5.530	1	1.026	2	1.649	20	3.286	0.2	5.9

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Total
Total Trucks Weighed	84	47	42	52	50	31	35	341
Total Vehicles Weighed	1038	869	1039	1156	1888	1261	2424	9675
Total 18-K ESAL	209.111	121.628	106.552	134.256	134.484	75.645	41.460	823.136
Total not weighed	412	415	373	463	710	619	1121	4113

Average Axle Weights in Tonnes by Vehicle Type

Alberta Transportation -- Leduc Scale Sit
From: Monday Jan 16 10:44 To: Monday May 15 13:05

Type	Axle 1	2	3	4	5	6	7	8	Total
3	2.2	3.6							5.8
4	4.3	6.3	3.2						13.9
5	2.3	4.1	2.1						8.5
6	4.9	6.3	8.1						19.3
7	2.6	4.6	2.4	2.6					12.2
8	3.3	3.8	3.1	2.5					12.8
9	4.1	5.6	5.6	4.4	5.0				24.8
10	3.4	5.0	3.7	2.9	3.1				18.2
11	3.7	5.1	4.6	4.0	4.2				21.5
12	4.8	6.4	6.2	7.4	6.5	6.6			[illegible]
13	3.5	4.1	4.2	4.2	3.8	3.2			[illegible]
14	4.0	5.7	5.7	5.3	5.6	4.7	5.1		[illegible]
15	3.9	5.7	5.9	5.1	5.7	4.9	4.8		[illegible]
16	3.6	5.9	4.5	3.7	3.6	3.1	3.1		27.[illegible]
17	3.3	4.1	4.2	4.4	4.3	3.6	3.2	2.8	29.9
18	3.7	5.6	5.6	4.8	5.4	5.1	3.4	3.9	37.4

Weight Distribution in Tonnes and Average 18-K ESAL by Type

Alberta Transportation -- Leduc Scale Sit
From: MondayJan 16 10:44 To: Monday May 15 13:05

Weight Range	Type 3 # 18-K	Type 4 # 18-K	Type 5 # 18-K	Type 6 # 18-K	Type 7 # 18-K	Type 8 # 18-K	Type 9 # 18-K	Type 10 # 18-K
< 2	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000
2-4	2200 0.016	0 0.000	33 0.009	0 0.000	1 0.004	0 0.000	0 0.000	0 0.000
4-6	3769 0.053	19 0.025	298 0.024	0 0.000	177 0.018	104 0.024	0 0.000	0 0.000
6-8	1730 0.201	90 0.173	176 0.089	0 0.000	337 0.031	115 0.064	1 0.222	0 0.000
8-10	949 0.467	345 0.373	145 0.203	0 0.000	250 0.107	74 0.227	48 0.208	3 0.092
10-12	455 0.953	721 0.414	123 0.401	0 0.000	261 0.229	136 0.298	820 0.285	3 0.168
12-14	164 1.820	946 0.591	79 0.613	0 0.000	211 0.340	141 0.482	2005 0.383	6 0.253
14-16	44 3.515	806 0.882	69 0.951	1 0.629	182 0.505	79 0.652	1738 0.482	8 0.291
16-18	13 6.179	432 1.241	29 1.403	0 0.000	158 0.730	57 0.878	1436 0.561	16 0.419
18-20	211.374	234 1.748	11 2.051	1 1.719	111 1.145	42 0.852	1272 0.639	9 0.511
20-22	114.215	120 2.380	1 3.923	3 2.226	66 1.737	29 1.352	1151 0.745	5 0.752
22-24	0 0.000	70 3.283	3 5.461	0 0.000	35 1.962	23 1.414	1062 0.849	0 0.000
24-26	0 0.000	33 4.540	111.869	0 0.000	34 2.635	13 1.735	1145 0.987	3 1.865
26-28	0 0.000	14 6.283	0 0.000	0 0.000	12 3.319	15 1.938	1262 1.147	2 1.394
28-30	0 0.000	3 7.959	0 0.000	0 0.000	12 3.639	15 2.665	1433 1.417	1 1.899
30-32	0 0.000	211.690	0 0.000	0 0.000	7 4.564	5 3.609	1657 1.760	1 2.559
32-34	0 0.000	0 0.000	0 0.000	0 0.000	1 8.190	2 3.845	1547 2.252	0 0.000
34-36	0 0.000	0 0.000	0 0.000	0 0.000	310.169	1 5.138	1437 2.820	1 4.498
36-38	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	2 6.061	1036 3.551	0 0.000
38-40	0 0.000	0 0.000	0 0.000	0 0.000	316.195	1 8.694	653 4.493	0 0.000
40-42	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	111.269	292 5.627	0 0.000
42-44	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	112.230	164 7.145	0 0.000
44-46	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	87 9.074	123.373
46-48	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	3010.650	0 0.000
48-50	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	1412.861	0 0.000
50-52	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	916.427	0 0.000
52-54	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	417.518	0 0.000
54-56	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000
56-58	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	125.473	0 0.000
58-60	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000
60-64	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000
64-68	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000
68-72	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000
72-76	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000
76-80	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000
80+up	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000
Total Average 18-K ESAL	9327 0.218	3835 0.902	968 0.322	5 1.805	1861 0.528	856 0.597	20304 1.539	59 1.024
Average Weight	5.8	13.9	8.5	19.3	12.2	12.8	24.8	18.2

Weight Distribution in Tonnes and Average 18-K ESAL by Type

Alberta Transportation -- Leduc Scale Sit
From: MondayJan16 10:44 To: Monday May 15 13:05

Weight Range	Type 11 # 18-K	Type 12 # 18-K	Type 13 # 18-K	Type 14 # 18-K	Type 15 # 18-K	Type 16 # 18-K	Type 17 # 18-K	Type 18 # 18-K	Type 19 # 18-K
< 2	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000
2-4	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000
4-6	5 0.021	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000
6-8	23 0.035	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000
8-10	26 0.093	0 0.000	0 0.000	0 0.000	1 0.164	0 0.000	0 0.000	0 0.000	0 0.000
10-12	41 0.235	13 0.232	6 0.200	13 0.245	12 0.238	0 0.000	0 0.000	0 0.000	32 0.263
12-14	62 0.373	20 0.383	33 0.247	115 0.297	158 0.334	0 0.000	0 0.000	2 0.228	131 0.345
14-16	52 0.550	23 0.570	80 0.298	361 0.365	302 0.396	0 0.000	0 0.000	5 0.302	183 0.365
16-18	41 0.601	13 0.615	70 0.303	371 0.447	178 0.429	2 0.256	18 0.206	9 0.265	211 0.434
18-20	29 0.617	4 0.586	87 0.376	174 0.545	107 0.428	3 0.333	29 0.221	26 0.288	224 0.472
20-22	20 0.723	7 0.943	101 0.455	70 0.638	81 0.434	11 0.339	46 0.270	41 0.310	152 0.493
22-24	39 0.928	3 0.740	80 0.568	56 0.691	94 0.453	13 0.448	53 0.311	34 0.302	105 0.502
24-26	29 1.050	4 1.366	74 0.639	28 0.677	48 0.514	11 0.587	44 0.333	70 0.363	80 0.645
26-28	43 1.360	3 0.804	61 0.836	20 0.722	40 0.636	13 0.792	31 0.450	69 0.437	112 0.602
28-30	31 1.777	0 0.000	39 1.094	17 0.997	55 0.740	14 0.967	36 0.510	81 0.548	92 0.704
30-32	39 2.239	4 1.464	30 1.398	20 0.915	50 0.867	8 1.354	46 0.722	105 0.600	105 0.943
32-34	27 2.621	7 2.203	38 1.664	26 1.059	86 1.016	4 1.357	25 0.767	98 0.756	125 1.004
34-36	27 3.484	18 2.414	24 1.908	40 1.190	93 1.197	8 1.758	30 1.071	112 0.923	126 1.245
36-38	21 4.338	34 2.757	12 2.638	51 1.237	93 1.461	5 2.057	28 1.288	119 1.110	157 1.478
38-40	4 7.943	59 3.014	6 3.092	92 1.558	149 1.734	2 2.157	29 1.509	134 1.349	158 1.843
40-42	6 6.964	58 3.699	4 3.237	132 1.681	216 1.979	0 0.000	23 1.832	98 1.524	137 2.127
42-44	7 8.404	71 4.250	3 4.230	168 2.067	257 2.299	1 5.592	13 2.111	108 1.907	134 2.292
44-46	112.360	49 5.061	1 5.648	269 2.367	297 2.815	0 0.000	9 2.569	117 2.217	115 2.417
46-48	0 0.000	50 5.748	211.207	227 2.903	208 3.335	0 0.000	9 3.177	93 2.514	92 2.797
48-50	0 0.000	29 6.838	1 8.691	196 3.427	235 3.984	0 0.000	6 3.346	57 2.845	111 2.945
50-52	0 0.000	15 8.158	2 9.127	246 4.115	220 4.657	0 0.000	3 4.307	45 3.378	124 2.881
52-54	0 0.000	5 9.652	0 0.000	233 4.706	137 5.522	0 0.000	0 0.000	31 3.862	110 3.139
54-56	0 0.000	112.268	0 0.000	151 5.580	52 6.662	0 0.000	0 0.000	10 5.375	122 3.662
56-58	0 0.000	115.358	0 0.000	70 6.710	30 7.754	0 0.000	116.427	9 5.656	91 3.956
58-60	0 0.000	117.647	0 0.000	25 8.484	14 9.119	0 0.000	0 0.000	11 7.243	89 4.761
60-64	0 0.000	0 0.000	0 0.000	29 9.734	1812.114	0 0.000	0 0.000	18 7.449	159 5.511
64-68	0 0.000	0 0.000	0 0.000	1612.818	515.111	0 0.000	0 0.000	0 0.000	41 7.525
68-72	0 0.000	0 0.000	0 0.000	215.778	222.543	0 0.000	0 0.000	120.650	1910.084
72-76	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	613.790
76-80	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	126.186
80+up	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000	0 0.000
Total Average 18-K ESAL	573 1.379	492 3.766	754 0.797	3218 2.347	3238 2.289	95 0.967	479 0.879	1503 1.537	3344 1.918
Average Weight	21.5	37.8	23.0	36.0	35.9	27.5	29.9	37.4	35.7

Car and Single Unit Truck Volumes by Hour and Day of Week

Alberta Transportation -- Leduc Scale Sit
From: Monday May 1 00:00 To: Monday May 8 00:00

Class A: Light Vehicles and Light Vehicles with Trailers (1, 2)
Class B: Single Unit Trucks (3, 4)

Time	Monday A	Monday B	Tuesday A	Tuesday B	Wednesday A	Wednesday B	Thursday A	Thursday B	Friday A	Friday B	Saturday A	Saturday B	Sunday A	Sunday B	Total A	Total %	Total B	Total %
0-1	56	3	22	2	31	2	11	1	31	2	34	4	48	0	233	0.7	14	1.
1-2	21	1	10	2	13	1	14	2	16	1	27	0	21	1	122	0.4	8	0.
2-3	13	0	11	2	11	3	10	2	11	2	21	2	21	0	98	0.3	11	0.
3-4	9	3	6	0	13	0	15	0	9	0	14	2	21	0	87	0.3	5	0.
4-5	20	3	12	2	15	2	15	2	12	1	13	0	16	2	103	0.3	12	1.
5-6	90	3	54	3	54	2	51	2	33	6	28	1	18	2	328	1.0	19	1.
6-7	234	7	174	8	161	9	164	11	155	6	70	3	42	1	1000	3.1	45	3.
7-8	226	3	194	16	174	10	186	11	156	4	126	3	69	1	1131	3.5	48	4.
8-9	205	4	194	8	205	13	195	5	193	7	212	9	138	6	1342	4.1	52	4.
9-10	232	14	205	6	250	14	254	10	227	15	308	12	211	10	1687	5.2	81	6.
10-11	230	16	217	5	226	15	230	18	279	12	387	13	259	2	1828	5.6	81	6.
11-12	240	14	240	7	205	14	207	14	240	15	382	9	370	8	1884	5.8	81	6.
12-13	236	9	237	10	227	10	257	15	200	13	426	5	366	9	1949	6.0	71	5.
13-14	219	11	247	12	228	8	240	17	373	9	358	10	421	10	2086	6.4	77	6.
14-15	282	11	225	12	239	16	241	16	406	18	362	7	537	12	2292	7.1	92	7.
15-16	289	11	284	14	275	21	285	13	459	15	386	13	618	20	2596	8.0	107	8.
16-17	301	3	271	8	296	9	333	12	533	13	349	7	711	12	2794	8.6	64	5.
17-18	214	5	277	7	255	7	296	11	506	13	343	12	608	12	2499	7.7	67	5.
18-19	172	8	191	7	204	14	203	11	525	9	312	7	662	11	2269	7.0	67	5.
19-20	183	11	169	10	183	10	184	6	430	14	249	6	715	16	2113	6.5	73	6.
20-21	143	2	108	7	145	7	147	3	364	13	207	11	560	8	1674	5.2	51	4.
21-22	113	7	64	6	117	3	123	4	225	8	131	7	370	5	1143	3.5	40	3.
22-23	57	5	72	4	95	3	70	3	137	8	135	2	230	4	796	2.5	29	2.
23-24	36	2	38	2	38	1	36	3	83	3	84	4	98	1	413	1.3	16	1.
Total	3821	156	3522	160	3660	194	3767	192	5603	207	4964	149	7130	153	32467	100.0	1211	100.
Subtotals (Peak Hours)																		
6-20	3263	127	3125	130	3128	170	3275	170	4682	163	4270	116	5727	130	27470	84.6	1006	83.
8-16	1933	90	1849	74	1855	111	1909	108	2377	104	2821	78	2920	77	15664	48.2	642	53.

Car and Single Unit Truck Volumes by Hour and Day of Week

Alberta Transportation -- Leduc Scale Sit
From: Monday May 8 00:00 To: Monday May 15 00:00

Class A: Light Vehicles and Light Vehicles with Trailers (1, 2)
Class B: Single Unit Trucks (3, 4)

	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday		Sunday		Total			
Time	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	%	B	%
0-1	37	5	33	1	31	2	23	2	35	1	41	0	40	1	240	0.7	12	1.
1-2	30	0	10	1	17	4	11	2	15	3	29	4	18	0	130	0.4	14	1.
2-3	9	1	8	1	13	2	11	4	9	2	23	1	20	0	93	0.3	11	0.
3-4	12	2	17	1	9	0	14	2	11	0	16	1	14	0	93	0.3	6	0.
4-5	30	2	19	1	21	0	12	2	13	2	9	2	12	1	116	0.4	10	0.
5-6	106	3	63	1	49	2	57	5	34	2	31	3	23	1	363	1.1	17	1.
6-7	247	14	162	9	167	6	161	10	151	2	79	4	25	1	992	3.1	46	3.
7-8	229	7	194	8	205	5	194	12	131	5	182	5	81	4	1216	3.8	46	3.
8-9	229	9	184	10	227	6	185	10	188	3	218	3	137	3	1368	4.2	44	3.
9-10	218	20	206	11	220	18	184	14	248	12	314	11	240	5	1630	5.1	91	7.
10-11	148	6	183	10	210	17	219	9	297	12	416	6	304	5	1777	5.5	65	5.
11-12	213	8	184	10	176	20	199	16	288	17	383	4	328	15	1771	5.5	90	7.
12-13	204	13	160	9	184	11	212	10	308	8	378	4	455	9	1901	5.9	64	5.
13-14	218	10	180	7	198	14	260	14	380	13	356	10	472	14	2064	6.4	82	7.
14-15	254	17	224	9	289	15	263	14	419	14	328	5	531	8	2308	7.2	82	7.
15-16	274	10	141	6	300	17	330	10	454	16	352	7	706	19	2557	7.9	85	7.
16-17	261	11	157	7	368	10	368	14	521	16	362	10	751	14	2788	8.6	82	7.
17-18	236	17	62	1	293	10	286	9	523	9	283	11	712	13	2395	7.4	70	6.
18-19	187	6	60	1	218	7	253	8	514	10	299	7	726	14	2257	7.0	53	4.
19-20	181	12	31	1	171	10	211	19	485	13	282	8	665	13	2026	6.3	76	6.
20-21	143	4	19	3	131	3	160	4	401	6	264	5	557	10	1675	5.2	35	3.
21-22	109	10	53	7	99	7	117	5	226	7	197	4	393	9	1194	3.7	49	4.
22-23	90	6	64	3	83	4	96	4	132	5	136	0	228	8	829	2.6	30	2.
23-24	43	0	52	5	27	3	48	3	106	1	83	2	129	2	488	1.5	16	1.
Total	3708	193	2466	123	3706	193	3874	202	5889	179	5061	117	7567	169	32271	100.0	1176	100.
Subtotals (Peak Hours)																		
6-20	3099	160	2128	99	3226	166	3325	169	4907	150	4232	95	6133	137	27050	83.8	976	83.
8-16	1758	93	1462	72	1804	118	1852	97	2582	95	2745	50	3173	78	15376	47.6	603	51.

5 Axle Semi's and Other Truck Volumes by Hour and Day of Week

Alberta Transportation -- Leduc Scale Sit
From: Monday May 1 00:00 To: Monday May 8 00:00

Class A:5 Axle Semi's and Equivalent (9)
Class B: Other Trucks (5-8, 10-19)

Time	Monday A	Monday B	Tuesday A	Tuesday B	Wednesday A	Wednesday B	Thursday A	Thursday B	Friday A	Friday B	Saturday A	Saturday B	Sunday A	Sunday B	Total A	Total %	Total B	Total %
0-1	6	2	9	6	7	8	10	9	11	5	10	4	4	5	57	3.2	39	2.
1-2	7	3	9	7	5	10	9	8	5	6	3	2	0	1	38	2.1	37	2.
2-3	5	6	6	5	4	5	6	6	9	8	3	3	1	0	34	1.9	33	1.
3-4	7	5	8	13	7	13	2	9	7	10	4	6	2	0	37	2.1	56	3.
4-5	8	4	7	12	9	13	8	10	6	11	10	4	1	5	49	2.7	59	3.
5-6	14	8	12	15	11	8	16	16	10	17	6	7	3	1	72	4.0	72	4.
6-7	12	12	16	17	10	21	20	10	15	7	7	6	6	2	86	4.8	75	4.
7-8	11	20	19	14	14	10	12	12	17	15	10	8	3	5	86	4.8	84	4.
8-9	14	17	7	9	16	14	16	18	16	15	5	10	4	7	78	4.4	90	5.
9-10	8	20	14	14	15	20	11	6	11	25	5	5	4	3	68	3.8	93	5.
10-11	21	15	15	16	10	16	12	19	19	19	6	14	5	7	88	4.9	106	5.
11-12	21	12	13	18	14	10	27	12	17	23	9	8	9	11	110	6.1	94	5.
12-13	16	13	14	14	21	9	15	17	14	16	12	9	3	6	95	5.3	84	4.
13-14	22	13	17	15	14	14	15	11	14	19	9	11	11	6	102	5.7	89	4.
14-15	15	16	12	13	22	18	19	12	12	15	11	6	5	9	96	5.4	89	4.
15-16	12	15	19	16	22	16	15	11	13	15	5	9	6	4	92	5.1	86	4.
16-17	11	7	12	12	16	9	25	6	13	8	7	6	2	12	86	4.8	60	3.
17-18	18	11	16	17	10	7	12	9	16	9	4	7	9	10	85	4.7	70	3.
18-19	13	11	10	14	11	17	15	17	9	15	8	6	10	8	76	4.2	88	4.
19-20	16	11	10	20	16	24	13	16	13	12	5	4	9	11	82	4.6	98	5.
20-21	15	9	6	17	12	13	7	15	12	9	5	3	7	7	64	3.6	73	4.
21-22	9	11	9	12	16	16	13	15	12	9	8	7	10	7	77	4.3	77	4.
22-23	15	14	10	11	7	14	11	15	10	13	8	5	6	4	67	3.7	76	4.
23-24	13	16	10	18	12	12	10	8	8	11	1	3	11	6	65	3.6	74	4.
Total	309	271	280	325	301	317	319	287	289	312	161	153	131	137	1790	100.0	1802	100.
Subtotals (Peak Hours)																		
6-20	210	193	194	209	211	205	227	176	199	213	103	109	86	101	1230	68.7	1206	66.
8-16	129	121	111	115	134	117	130	106	116	147	62	72	47	53	729	40.7	731	40.

5 Axle Semi's and Other Truck Volumes by Hour and Day of Week

Alberta Transportation -- Leduc Scale Sit
From: Monday May 8 00:00 To: Monday May 15 00:00

Class A:5 Axle Semi's and Equivalent (9)
Class B: Other Trucks (5-8, 10-19)

Time	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday		Sunday		Total			
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	%	B	%
0-1	6	4	7	7	11	13	7	9	7	9	8	6	5	2	51	2.8	50	2.
1-2	13	5	7	8	4	7	6	6	8	7	3	5	6	0	47	2.6	38	2.
2-3	6	10	6	5	5	5	8	11	6	12	7	5	3	1	41	2.3	49	2.
3-4	8	7	9	6	6	10	6	11	5	15	7	3	0	1	41	2.3	53	2.
4-5	11	8	11	13	9	11	11	11	6	10	6	5	2	2	56	3.1	60	3.
5-6	14	12	14	10	17	18	13	6	13	10	5	7	2	3	78	4.3	66	3.
6-7	13	18	14	16	15	18	18	14	17	13	7	6	3	1	87	4.8	86	4.
7-8	9	19	15	27	12	12	14	13	13	6	11	10	3	5	77	4.3	92	5.
8-9	12	8	14	16	22	14	17	19	17	16	7	9	5	7	94	5.2	89	4.
9-10	17	15	16	15	13	14	15	10	12	15	8	8	4	6	85	4.7	83	4.
10-11	8	9	19	13	17	14	14	16	14	14	10	11	5	4	87	4.8	81	4.
11-12	17	17	21	14	21	15	23	20	20	18	3	7	8	6	113	6.3	97	5.
12-13	24	11	18	11	18	18	19	24	19	17	6	10	6	5	110	6.1	96	5.
13-14	12	23	16	15	20	13	17	18	15	17	3	11	4	8	87	4.8	105	5.
14-15	17	18	18	23	16	15	24	14	16	18	3	14	17	6	111	6.2	108	5.
15-16	15	11	8	4	16	17	14	16	15	13	6	4	4	6	78	4.3	71	3.
16-17	7	15	4	5	12	14	9	12	14	12	7	11	8	9	61	3.4	78	4.
17-18	14	20	0	0	15	14	15	15	17	19	4	6	8	7	73	4.1	81	4.
18-19	11	20	1	0	12	13	16	13	11	16	7	7	5	11	63	3.5	80	4.
19-20	17	17	0	0	13	13	11	13	24	23	5	7	6	8	76	4.2	81	4.
20-21	16	13	0	0	21	19	10	19	13	8	8	11	14	10	82	4.6	80	4.
21-22	11	13	3	9	18	18	12	24	13	15	5	3	6	8	68	3.8	90	4.
22-23	12	12	14	8	11	20	14	15	7	12	3	6	11	5	72	4.0	78	4.
23-24	11	10	9	11	13	8	8	11	7	7	1	3	10	11	59	3.3	61	3.
Total	301	315	244	236	337	333	321	340	309	322	140	175	145	132	1797	100.0	1853	100.
Subtotals (Peak Hours)																		
6-20	193	221	164	159	222	204	226	217	224	217	87	121	86	89	1202	66.9	1228	66.
8-16	122	112	130	111	143	120	143	137	128	128	46	74	53	48	765	42.6	730	39.

Numbers of Truck Axles by Weight (Tonnes)

Alberta Transportation -- Leduc Scale Sit
From: Monday Jan 16 10:44 To: Monday May 15 13:05

Lane:1 19377 5-axle semi's (Type 9). Front axles:41 (8)
Lane:2 927 5-axle semi's (Type 9). Front axles:51 (8)

Front Axles Weight	#	Tandem Front Axles Weight	#	Single Axles Weight	#	Tandem Axles Weight	#	Tridem Axles Weight	#
< 2.0	6247	< 4.0	3	< 2.0	4236	< 4.0	6994	< 4.0	77
2.0-2.5	1810	4.0-5.0	5	2.0-2.5	4194	4.0-5.0	5518	4.0-5.0	145
2.5-3.0	3274	5.0-6.0	1	2.5-3.0	3890	5.0-6.0	6449	5.0-6.0	238
3.0-3.5	7272	6.0-7.0	5	3.0-3.5	3043	6.0-7.0	5251	6.0-7.0	195
3.5-4.0	11595	7.0-8.0	3	3.5-4.0	2501	7.0-8.0	4472	7.0-8.0	64
4.0-4.5	10404	8.0-9.0	3	4.0-4.5	1917	8.0-9.0	4258	8.0-9.0	29
4.5-5.0	5917	9.0-10.0	10	4.5-5.0	1658	9.0-10.0	4017	9.0-10.0	24
5.0-5.5	2607	10.0-11.0	22	5.0-5.5	1545	10.0-11.0	4152	10.0-11.0	22
5.5-6.0	906	11.0-12.0	23	5.5-6.0	1507	11.0-12.0	4500	11.0-12.0	20
6.0-6.5	375	12.0-13.0	17	6.0-6.5	1559	12.0-13.0	5530	12.0-13.0	22
6.5-7.0	168	13.0-14.0	12	6.5-7.0	1369	13.0-14.0	6069	13.0-14.0	40
7.0-7.5	91	14.0-15.0	5	7.0-7.5	1207	14.0-15.0	5861	14.0-15.0	48
7.5-8.0	64	15.0-16.0	4	7.5-8.0	920	15.0-16.0	5082	15.0-16.0	59
8.0-8.5	38	16.0-17.0	3	8.0-8.5	618	16.0-17.0	4018	16.0-17.0	58
8.5-9.0	16	17.0-18.0	3	8.5-9.0	368	17.0-18.0	2316	17.0-18.0	93
9.0-9.5	3	18.0-19.0	0	9.0-9.5	259	18.0-19.0	1131	18.0-19.0	103
9.5-10.0	3	19.0-20.0	0	9.5-10.0	168	19.0-20.0	530	19.0-20.0	155
10.0-10.5	1	20.0-21.0	0	10.0-10.5	96	20.0-21.0	325	20.0-21.0	160
10.5-11.0	1	21.0-22.0	0	10.5-11.0	54	21.0-22.0	221	21.0-22.0	153
11.0-11.5	0	22.0-23.0	0	11.0-11.5	40	22.0-23.0	121	22.0-23.0	124
11.5-12.0	0	23.0-24.0	0	11.5-12.0	21	23.0-24.0	79	23.0-24.0	126
12.0+up	0	24.0-25.0	0	12.0-12.5	13	24.0-25.0	51	24.0-25.0	94
		25.0-26.0	0	12.5-13.0	11	25.0-26.0	18	25.0-26.0	49
		26.0-27.0	0	13.0-13.5	6	26.0-27.0	11	26.0-27.0	13
		27.0-28.0	0	13.5-14.0	5	27.0-28.0	3	27.0-28.0	7
		28.0-29.0	0	14.0-14.5	6	28.0-29.0	2	28.0-29.0	5
		29.0-30.0	0	14.5-15.0	1	29.0-30.0	1	29.0-30.0	2
		30.0+up	0	15.0-15.5	0	30.0+up	0	30.0-31.0	1
				15.5-16.0	0			31.0-32.0	0
				16.0+up	0			32.0-33.0	0
								33.0-34.0	0
								34.0-35.0	0
								35.0-36.0	0
								36.0-37.0	0
								37.0+up	0
Total	50792		119		31212		76980		2126
Average Weight	3.6		11.1		4.0		10.2		14.8

Traffic Volumes by Speed Range

Alberta Transportation -- Leduc Scale Sit
From: Monday May 1 00:00 To: Monday May 8 00:00

Speed Range	Monday		Tuesday		Wednesday		Thursday		Friday		Average Weekday		Saturday		Sunday		Average Day of Week			
km/hr	cars	trks	cars	trks	cars	trks	cars	trks	cars	trks	cars	trks	cars	trks	cars	trks	cars	trks	%	cum %
0-50	0	0	0	0	1	0	0	0	19	4	4	0	2	0	1	0	3	0	0.1	0.1
51-75	0	4	6	1	5	1	1	2	50	14	12	4	2	0	0	2	9	3	0.2	0.3
76-85	9	6	15	14	16	14	12	16	33	20	17	14	20	3	18	8	17	11	0.5	0.9
86-90	30	34	27	34	30	49	31	48	37	41	31	41	40	23	34	20	32	35	1.3	2.1
91-95	31	84	59	88	61	111	57	86	78	83	57	90	65	42	102	50	64	77	2.7	4.8
96-100	136	110	137	127	100	132	119	124	182	108	134	120	166	84	231	61	153	106	4.9	9.7
101-105	262	151	277	185	262	185	24[illegible]	194	399	191	289	181	389	84	524	91	336	154	9.2	18.9
106-110	574	176	509	155	566	159	526	156	771	177	589	164	744	101	1151	89	691	144	15.7	34.6
111-115	813	108	820	102	839	108	902	96	1246	93	924	101	1151	66	1692	52	1066	89	21.7	56.3
116-120	888	43	783	36	824	31	865	54	1195	48	911	42	1119	33	1588	28	1037	39	20.2	76.5
121-125	618	13	509	17	542	16	569	16	906	23	632	17	710	21	1096	13	710	17	13.7	90.2
126-135	372	7	310	6	342	5	353	6	564	5	388	5	445	4	573	6	422	5	8.0	98.2
136-200	88	0	70	0	72	1	67	0	123	1	84	0	111	2	120	1	93	0	1.8	100.0
Total	3821	736	3522	765	3660	812	3767	798	5603	808	4074	783	4964	463	7130	421	4638	686		
Average Speed	115.7	104.3	114.7	103.8	115.1	103.1	115.4	103.6	114.8	103.0	115.1	103.6	115.0	105.3	115.0	104.3	115.1	103.8		
Combined Avg. Speed	113.9		112.8		112.9		113.3		113.4		113.3		114.2		114.4		113.6			

Traffic Volumes by Speed Range

Alberta Transportation -- Leduc Scale Sit
From: Monday May 8 00:00 To: Monday May 15 00:00

Speed Range km/hr	Monday cars	Monday trks	Tuesday cars	Tuesday trks	Wednesday cars	Wednesday trks	Thursday cars	Thursday trks	Friday cars	Friday trks	Average Weekday cars	Average Weekday trks	Saturday cars	Saturday trks	Sunday cars	Sunday trks	Average Day of Week cars	Average Day of Week trks	Average Day of Week %	Average Day of Week cum %
0-50	5	1	1	0	0	0	0	1	0	0	1	0	0	0	2	0	1	0	0.0	0.0
51-75	105	28	1	3	1	1	1	1	3	2	22	3	0	1	5	0	16	5	0.4	0.4
76-85	117	41	7	6	18	16	21	22	15	10	35	[illegible]	14	9	11	8	29	16	0.8	1.3
86-90	107	54	18	34	29	41	32	44	37	51	44	[illegible]	25	15	34	13	40	36	1.4	2.7
91-95	153	99	36	61	37	89	57	99	84	75	73	[illegible]	75	52	70	38	73	73	2.8	5.5
96-100	199	114	93	108	128	165	149	176	161	127	145	[illegible]	150	62	208	74	155	118	5.2	10.6
101-105	300	157	183	132	258	203	327	182	415	171	296	159	335	86	470	99	326	147	8.9	19.6
106-110	538	144	356	120	568	194	622	168	774	175	571	160	725	96	1075	80	665	139	15.2	34.8
111-115	737	89	528	85	843	84	903	103	1403	109	882	94	1159	64	1774	78	1049	87	21.5	56.2
116-120	676	53	560	32	839	39	842	44	1285	54	840	44	1145	25	1743	41	1012	41	19.9	76.1
121-125	435	18	394	14	529	24	556	18	976	29	578	20	757	17	1228	12	696	18	13.5	89.6
126-135	280	11	228	7	370	7	298	5	626	5	360	7	543	5	809	3	450	6	8.6	98.2
136-200	56	0	61	1	86	0	66	0	110	2	75	0	133	0	138	0	92	0	1.8	100.0
Total	3708	809	2466	603	3706	863	3874	863	5889	810	[illegible]	789	5061	432	7567	446	4610	689		
Average Speed	110.5	101.5	115.4	104.0	115.3	103.5	114.4	103.0	115.7	104.5	[illegible]	103.3	115.9	104.6	115.9	105.4	115.0	103.6		
Combined Avg. Speed	108.9		113.1		113.1		112.3		114.4		112.5		115.0		115.3		113.5			

Average Axle Spacing in Meters by Vehicle Type

Alberta Transportation -- Leduc Scale Site
From: Monday Jan16 10:44 To: Monday May 15 13:05

Type	Number	L1	S.D.	L2	S.D.	L3	S.D.	L4	S.D.	L5	S.D.	L6	S.D.	L7	S.D.	Total	
3	9327	4.76	(1.01)													4.76	(1.01)
4	3835	6.41	(1.10)	1.30	(0.14)											7.71	(1.01)
5	968	4.30	(0.83)	7.16	(1.93)											11.46	(2.44)
6	5	1.44	(0.07)	3.74	(0.15)											5.19	(0.21)
7	1861	4.38	(0.75)	8.28	(2.18)	1.20	(0.31)									13.76	(2.72)
8	856	4.44	(1.22)	3.07	(2.11)	5.63	(3.12)									13.14	(3.00)
9	20304	5.02	(0.71)	1.47	(0.10)	9.41	(1.36)	1.46	(0.20)							17.36	(1.63)
10	59	4.32	(0.64)	6.24	(0.86)	3.13	(0.58)	6.50	(0.33)							20.19	(0.83)
11	573	5.14	(0.99)	2.67	(2.67)	6.48	(3.27)	2.94	(1.59)							17.23	(2.89)
12	492	5.20	(0.54)	1.46	(0.09)	5.10	(1.14)	4.74	(1.21)	1.40	(0.19)					17.89	(1.54)
13	754	4.17	(0.72)	1.48	(0.11)	6.00	(0.49)	2.99	(0.50)	6.54	(0.74)					21.18	(1.23)
14	3218	4.85	(0.61)	1.50	(0.10)	6.17	(0.53)	1.72	(0.16)	5.56	(0.51)	1.61	(0.17)			21.43	(1.11)
15	3238	4.60	(0.65)	1.50	(0.10)	7.35	(1.66)	1.56	(0.16)	3.74	(0.55)	4.91	(1.42)			23.66	(2.79)
16	95	4.23	(0.10)	6.19	(0.13)	3.11	(0.15)	6.29	(0.15)	3.12	(0.13)	6.28	(0.15)			29.23	(0.65)
17	479	3.91	(0.37)	1.46	(0.10)	5.97	(0.47)	2.90	(0.17)	6.55	(0.36)	2.93	(0.53)	6.52	(0.43)	30.23	(1.11)
18	1503	4.22	(0.54)	1.47	(0.10)	8.50	(2.10)	1.53	(0.20)	3.52	(0.48)	8.44	(2.67)	1.51	(0.23)	29.19	(4.68)

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Password:
Password:

APPENDIX B

SAMPLE PAVEMENT THICKNESS OUTPUT FROM THE "PCAPAV" PROGRAM

Design Parameters

The Average daily truck traffic (2 way) input is the truck volumes on the right design lanes.

The ADTT (both directions) = 1720

Proportion of trucks using right design lane = 0.9

Projection factor for 20 years = 1.5

Projection factor for 40 years = 2.2

Two way 20 year design ADTT = 1720 x 0.9 x 1.5 = 2322

Two way 40 year design ADTT = 1720 x 0.9 x 2.2 = 3405

Expected axle repetitions within the design period is obtained by multiplying the number of axles/1000 trucks and the design number of trucks (one direction)

One Dir. Design # Trucks = Design ADTT x 365 x design life

Number of Trucks for 20 years design life = 8,475,300

Number of Trucks for 40 years design life = 24,856,500

PCAPAV(TM) 1.10

Proprietary Software of PORTLAND CEMENT ASSOCIATION

Project: Trial:

Engineer: J. Bervell

Input Data:

Subgrade / Subbase K 150.0 PCI

Modulus of Rupture MR 600.0 PSI

Avg. Daily Truck Traffic (2 way) ADTT 2320.00

Design Life 20 years

Aggregate Interlock Joints

No Concrete Shoulders

Load Safety Factor 1.2

Estimated Pavement Thickness 12.0 IN

A X L E L O A D S

Axles per 1000 Trucks

Single		Tandem	
32	0.20	68	0.04
30	0.36	64	0.10
28	0.54	60	0.59
26	1.19	56	1.94
24	3.36	52	4.47
22	8.72	48	11.70
20	17.84	44	31.49
18	39.58	40	100.56
16	65.30	36	203.53
14	99.77	32	276.37

Design Thickness =12.5 Inches

SAL	*LSF	Load Repetitions Axle/ 1000	Expected Reps	---Fatigue Analysis----- Stress Ratio	Allowable Reps	Fatigue Consump	----Erosion Analysis--- Power	Allowable Reps	Erosion
32	38.4	0.20	1594.	0.462	11233758.	0.02	35.621	1754767.	0.10
30	36.0	0.36	3048.	0.435	**********	0.00	31.307	2604290.	0.12
28	33.6	0.54	4573.	0.408	**********	0.00	27.272	4032077.	0.11
26	31.2	1.19	10077.	0.380	**********	0.00	23.515	6602972.	0.15
24	28.8	3.36	28452.	0.353	**********	0.00	20.037	11700384.	0.24
22	26.4	8.72	73841.	0.325	**********	0.00	16.836	23393564.	0.32
20	24.0	17.84	151069.	0.297	**********	0.00	13.914	57873323.	0.26
18	21.6	39.58	335163.	0.269	**********	0.00	11.271	236419948.	0.14
16	19.2	65.30	552960.	0.241	**********	0.00	8.905	**********	0.00
14	16.8	99.77	844852.	0.212	**********	0.00	6.818	**********	0.00

TAL	*LSF	Axle/ 1000	Expected Reps	Stress Ratio	Allowable Reps	Fatigue Consump	Power	Allowable Reps	Erosion
68	81.6	0.04	339.	0.484	1848619.	0.02	77.827	185133.	0.18
64	76.8	0.10	847.	0.457	20469560.	0.00	68.941	260400.	0.33
60	72.0	0.59	4996.	0.430	**********	0.00	60.592	374977.	1.33
56	67.2	1.94	16428.	0.403	**********	0.00	52.783	555311.	2.9[illegible]
52	62.4	4.47	37852.	0.376	**********	0.00	45.512	850934.	4.45
48	57.6	11.70	99076.	0.349	**********	0.00	38.779	1360980.	7.28
44	52.8	31.49	266657.	0.321	**********	0.00	32.585	2301408.	11.59
40	48.0	100.56	851542.	0.294	**********	0.00	26.930	4200657.	20.27
36	43.2	203.53	1723492.	0.266	**********	0.00	21.813	8584485.	20.08
32	38.4	276.37	2340301.	0.238	**********	0.00	17.235	21190308.	11.04

Total Fatigue Used = 0.04 Erosion Damage = 80.95

12.0 Inch Thickness Inadequate, Fatigue Used= 0.25 Erosion Damage = 106.77

PCAPAV(TM) 1.10
Proprietary Software of PORTLAND CEMENT ASSOCIATION

Project: Trial2
Engineer: J. Bervell
Input Data:
Subgrade / Subbase K 150.0 PCI
Modulus of Rupture MR 600.0 PSI
Avg. Daily Truck Traffic (2 way) ADTT 2320.00
Design Life 20 years
Doweled Joints
No Concrete Shoulders
Load Safety Factor 1.2
Estimated Pavement Thickness 12.5 IN

A X L E L O A D S
Axles per 1000 Trucks

Single		Tandem	
32	0.20	68	0.04
30	0.36	64	0.10
28	0.54	60	0.59
26	1.19	56	1.94
24	3.36	52	4.47
22	8.72	48	11.70
20	17.84	44	31.49
18	39.58	40	100.56
16	65.30	36	203.53
14	99.77	32	276.37

Design Thickness =10.0 Inches

Load Repetitions ---Fatigue Analysis----- ----Erosion Analysis---

SAL	*LSF	Axle/ 1000	Expected Reps	Stress Ratio	Allowable Reps	Fatigue Consump	Power	Allowable Reps	Erosion
32	38.4	0.20	1694.	0.632	12735.	13.30	36.667	1609998.	0.11
30	36.0	0.36	3048.	0.595	35833.	8.51	32.227	2383451.	0.13
28	33.6	0.54	4573.	0.557	101242.	4.52	28.073	3676872.	0.12
26	31.2	1.19	10077.	0.520	327105.	3.08	24.206	5988969.	0.17
24	28.8	3.36	28452.	0.482	2065008.	1.38	20.625	10522756.	0.27
22	26.4	8.72	73841.	0.444	**********	0.00	17.331	20733530.	0.36
20	24.0	17.84	151069.	0.406	**********	0.00	14.323	49792510.	0.30
18	21.6	39.58	335163.	0.368	**********	0.00	11.602	186418318.	0.18
16	19.2	65.30	552960.	0.329	**********	0.00	9.167	**********	0.00
14	16.8	99.77	844852.	0.291	**********	0.00	7.018	**********	0.00

TAL	*LSF	Axle/ 1000	Expected Reps	Stress Ratio	Allowable Reps	Fatigue Consump	Power	Allowable Reps	Erosion
68	81.6	0.04	339.	0.622	16837.	2.01	64.485	314710.	0.11
64	76.8	0.10	847.	0.587	43887.	1.93	57.121	443731.	0.19
60	72.0	0.59	4996.	0.553	114810.	4.35	50.204	641618.	0.78
56	67.2	1.94	16428.	0.518	349217.	4.70	43.733	956442.	1.72
52	62.4	4.47	37852.	0.483	1924856.	1.97	37.709	1480589.	2.56
48	57.6	11.70	99076.	0.448	**********	0.00	32.131	2405580.	4.12
44	52.8	31.49	266657.	0.413	**********	0.00	26.999	4170365.	6.39
40	48.0	100.56	851542.	0.378	**********	0.00	22.313	7932319.	10.74
36	43.2	203.53	1723492.	0.342	**********	0.00	18.074	17464543.	9.87
32	38.4	276.37	2340301.	0.306	**********	0.00	14.280	50567379.	4.63

Total Fatigue Used = 45.74 Erosion Damage = 42.73

9.5 Inch Thickness Inadequate, Fatigue Used= 160.43 Erosion Damage = 67.11

PCAPAV(TM) 1.10

Proprietary Software of PORTLAND CEMENT ASSOCIATION

Project: Trial3
Engineer: J. Bervell
Input Data:
Subgrade / Subbase K 150.0 PCI
Modulus of Rupture MR 600.0 PSI
Avg. Daily Truck Traffic (2 way) ADTT 2320.00
Design Life 20 years
Aggregate Interlock Joints
Concrete Shoulders
Load Safety Factor 1.2
Estimated Pavement Thickness 12.5 IN

A X L E L O A D S

Axles per 1000 Trucks

Single		Tandem	
32	0.20	68	0.04
30	0.36	64	0.10
28	0.54	60	0.59
26	1.19	56	1.94
24	3.36	52	4.47
22	8.72	48	11.70
20	17.84	44	31.49
18	39.58	40	100.56
16	65.30	36	203.53
14	99.77	32	276.37

Design Thickness =10.5 Inches

		Load Repetitions		---Fatigue Analysis-----			----Erosion Analysis---		
SAL	*LSF	Axle/ 1000	Expected Reps	Stress Ratio	Allowable Reps	Fatigue Consump	Power	Allowable Reps	Erosion
32	38.4	0.20	1694.	0.488	1464186.	0.12	21.800	549613.	0.31
30	36.0	0.36	3048.	0.459	16054640.	0.02	19.160	885763.	0.34
28	33.6	0.54	4573.	0.430	**********	0.00	16.691	1551585.	0.29
26	31.2	1.19	10077.	0.401	**********	0.00	14.391	3100500.	0.33
24	28.8	3.36	28452.	0.372	**********	0.00	12.262	7915862.	0.36
22	26.4	8.72	73841.	0.343	**********	0.00	10.304	38967453.	0.19
20	24.0	17.84	151069.	0.314	**********	0.00	8.516	**********	0.00
18	21.6	39.58	335163.	0.284	**********	0.00	6.898	**********	0.00
16	19.2	65.30	552960.	0.254	**********	0.00	5.450	**********	0.00
14	16.8	99.77	844852.	0.224	**********	0.00	4.173	**********	0.00

TAL	*LSF	Axle/ 1000	Expected Reps	Stress Ratio	Allowable Reps	Fatigue Consump	Power	Allowable Reps	Erosion
68	81.6	0.04	339.	0.466	7549241.	0.00	39.372	83109.	0.41
64	76.8	0.10	847.	0.440	**********	0.00	34.876	119481.	0.71
60	72.0	0.59	4996.	0.414	**********	0.00	30.653	177675.	2.81
56	67.2	1.94	16428.	0.388	**********	0.00	26.702	275869.	5.95
52	62.4	4.47	37852.	0.362	**********	0.00	23.024	453695.	8.34
48	57.6	11.70	99076.	0.336	**********	0.00	19.618	809390.	12.24
44	52.8	31.49	266657.	0.309	**********	0.00	16.484	1637448.	16.28
40	48.0	100.56	851542.	0.283	**********	0.00	13.623	4151030.	20.51
36	43.2	203.53	1723492.	0.256	**********	0.00	11.035	18307500.	9.41
32	38.4	276.37	2340301.	0.229	**********	0.00	8.719	**********	0.00

Total Fatigue Used = 0.14 Erosion Damage = 78.50

10.0 Inch Thickness Inadequate, Fatigue Used= 0.86 Erosion Damage = 121.19

PCAPAV(TM) 1.10

Proprietary Software of PORTLAND CEMENT ASSOCIATION

Project: Trial4

Engineer: J. Bervell

Input Data:

Subgrade / Subbase K 150.0 PCI

Modulus of Rupture MR 600.0 PSI

Avg. Daily Truck Traffic (2 way) ADTT 2320.00

Design Life 20 years

Doweled Joints

Concrete Shoulders

Load Safety Factor 1.2

Estimated Pavement Thickness 12.5 IN

A X L E L O A D S

Axles per 1000 Trucks

Single		Tandem	
32	0.20	68	0.04
30	0.36	64	0.10
28	0.54	60	0.59
26	1.19	56	1.94
24	3.36	52	4.47
22	8.72	48	11.70
20	17.84	44	31.49
18	39.58	40	100.56
16	65.30	36	203.53
14	99.77	32	276.37

Design Thickness =8.5 Inches

Load Repetitions ---Fatigue Analysis----- ----Erosion Analysis---

SAL	*LSF	Axle/ 1000	Expected Reps	Stress Ratio	Allowable Reps	Fatigue Consump	Power	Allowable Reps	Erosion
32	38.4	0.20	1694.	0.649	7927.	21.37	22.356	503510.	0.34
30	36.0	0.36	3048.	0.611	22934.	13.29	19.649	805849.	0.38
28	33.6	0.54	4573.	0.572	66639.	6.86	17.116	1396322.	0.33
26	31.2	1.19	10077.	0.534	201149.	5.01	14.758	2737826.	0.37
24	28.8	3.36	28452.	0.495	966552.	2.94	12.575	6714798.	0.42
22	26.4	8.72	73841.	0.456	22768041.	0.32	10.567	28788457.	0.26
20	24.0	17.84	151069.	0.417	**********	0.00	8.733	**********	0.00
18	21.6	39.58	335163.	0.378	**********	0.00	7.074	**********	0.00
16	19.2	65.30	552960.	0.338	**********	0.00	5.589	**********	0.00
14	16.8	99.77	844852.	0.298	**********	0.00	4.279	**********	0.00

TAL	*LSF	Axle/ 1000	Expected Reps	Stress Ratio	Allowable Reps	Fatigue Consump	Power	Allowable Reps	Erosion
68	81.6	0.04	339.	0.598	32969.	1.03	34.195	127015.	0.27
64	76.8	0.10	847.	0.565	82798.	1.02	30.290	184656.	0.46
60	72.0	0.59	4996.	0.531	218404.	2.29	26.622	278954.	1.79
56	67.2	1.94	16428.	0.498	837822.	1.96	23.191	443114.	3.71
52	62.4	4.47	37852.	0.465	8686297.	0.44	19.996	754365.	5.02
48	57.6	11.70	99076.	0.431	**********	0.00	17.038	1423478.	6.96
44	52.8	31.49	266657.	0.397	**********	0.00	14.317	3191005.	8.36
40	48.0	100.56	851542.	0.363	**********	0.00	11.832	10252115.	8.31
36	43.2	203.53	1723492.	0.329	**********	0.00	9.584	142083093.	1.21
32	38.4	276.37	2340301.	0.294	**********	0.00	7.573	**********	0.00

Total Fatigue Used = 56.53 Erosion Damage = 38.17

8.0 Inch Thickness Inadequate, Fatigue Used= 252.91 Erosion Damage = 75.26

PCAPAV(TM) 1.10
Proprietary Software of PORTLAND CEMENT ASSOCIATION

Project: Trial5
Engineer: J. Bervell
Input Data:
Subgrade / Subbase K 150.0 PCI
Modulus of Rupture MR 600.0 PSI
Avg. Daily Truck Traffic (2 way) ADTT 3405.00
Design Life 40 years
Aggregate Interlock Joints
No Concrete Shoulders
Load Safety Factor 1.2
Estimated Pavement Thickness 13.0 IN

AXLE LOADS			
Axles per 1000 Trucks			
Single		Tandem	
32	0.20	68	0.04
30	0.36	64	0.10
28	0.54	60	0.59
26	1.19	56	1.94
24	3.36	52	4.47
22	8.72	48	11.70
20	17.84	44	31.49
18	39.58	40	100.56
16	65.30	36	203.53
14	99.77	32	276.37

NO ADEQUATE THICKNESS FOUND

14.0 Inch Thickness Inadequate, Fatigue Used= 0.00 Erosion Damage = 105.70

PCAPAV(TM) 1.10

Proprietary Software of PORTLAND CEMENT ASSOCIATION

Project: Trial7
Engineer: J. Bervell
Input Data:
Subgrade / Subbase K 150.0 PCI
Modulus of Rupture MR 600.0 PSI
Avg. Daily Truck Traffic (2 way) ADTT 3405.00
Design Life 40 years
Aggregate Interlock Joints
Concrete Shoulders
Load Safety Factor 1.2
Estimated Pavement Thickness 10.0 IN

A X L E L O A D S

Axles per 1000 Trucks

Single		Tandem	
32	0.20	68	0.04
30	0.36	64	0.10
28	0.54	60	0.59
26	1.19	56	1.94
24	3.36	52	4.47
22	8.72	48	11.70
20	17.84	44	31.49
18	39.58	40	100.56
16	65.30	36	203.53
14	99.77	32	276.37

Design Thickness =11.5 Inches

Load Repetitions ---Fatigue Analysis----- ----Erosion Analysis---

SAL	*LSF	Axle/ 1000	Expected Reps	Stress Ratio	Allowable Reps	Fatigue Consump	Power	Allowable Reps	Erosion
32	38.4	0.20	4971.	0.431	**********	0.00	17.436	1289458.	0.39
30	36.0	0.36	8948.	0.406	**********	0.00	15.325	2276939.	0.39
28	33.6	0.54	13423.	0.380	**********	0.00	13.349	4652090.	0.29
26	31.2	1.19	29579.	0.355	**********	0.00	11.511	12654880.	0.23
24	28.8	3.36	83518.	0.329	**********	0.00	9.808	84496323.	0.10
22	26.4	8.72	216749.	0.303	**********	0.00	8.241	**********	0.00
20	24.0	17.84	443440.	0.277	**********	0.00	6.811	**********	0.00
18	21.6	39.58	983820.	0.251	**********	0.00	5.517	**********	0.00
16	19.2	65.30	1623129.	0.225	**********	0.00	4.359	**********	0.00
14	16.8	99.77	2479933.	0.198	**********	0.00	3.337	**********	0.00

TAL	*LSF	Axle/ 1000	Expected Reps	Stress Ratio	Allowable Reps	Fatigue Consump	Power	Allowable Reps	Erosion
68	81.6	0.04	994.	0.419	**********	0.00	33.493	135078.	0.74
64	76.8	0.10	2486.	0.396	**********	0.00	29.668	196754.	1.26
60	72.0	0.59	14665.	0.373	**********	0.00	26.076	298028.	4.92
56	67.2	1.94	48222.	0.349	**********	0.00	22.715	475271.	10.15
52	62.4	4.47	111109.	0.326	**********	0.00	19.586	813997.	13.65
48	57.6	11.70	290821.	0.302	**********	0.00	16.688	1551524.	18.74
44	52.8	31.49	782731.	0.278	**********	0.00	14.023	3546037.	22.07
40	48.0	100.56	2499570.	0.255	**********	0.00	11.589	11981138.	20.86
36	43.2	203.53	5059043.	0.231	**********	0.00	9.387	260143849.	1.94
32	38.4	276.37	6869591.	0.206	**********	0.00	7.417	**********	0.00

Total Fatigue Used = 0.00 Erosion Damage = 95.74

11.0 Inch Thickness Inadequate, Fatigue Used= 0.03 Erosion Damage = 149.22

PCAPAV(TM) 1.10
Proprietary Software of PORTLAND CEMENT ASSOCIATION

Project: Trial6
Engineer: J. Bervell
Input Data:
Subgrade / Subbase K 150.0 PCI
Modulus of Rupture MR 600.0 PSI
Avg. Daily Truck Traffic (2 way) ADTT 3405.00
Design Life 40 years
Doweled Joints
No Concrete Shoulders
Load Safety Factor 1.2
Estimated Pavement Thickness 10.0 IN

AXLE LOADS
Axles per 1000 Trucks

Single		Tandem	
32	0.20	68	0.04
30	0.36	64	0.10
28	0.54	60	0.59
26	1.19	56	1.94
24	3.36	52	4.47
22	8.72	48	11.70
20	17.84	44	31.49
18	39.58	40	100.56
16	65.30	36	203.53
14	99.77	32	276.37

Design Thickness =10.5 Inches

Load Repetitions ---Fatigue Analysis----- ----Erosion Analysis---

SAL	*LSF	Axle/ 1000	Expected Reps	Stress Ratio	Allowable Reps	Fatigue Consump	Power	Allowable Reps	Erosion
32	38.4	0.20	4971.	0.590	40785.	12.19	31.752	2494714.	0.20
30	36.0	0.36	8948.	0.555	107157.	8.35	27.907	3746655.	0.24
28	33.6	0.54	13423.	0.521	319969.	4.19	24.310	5901020.	0.23
26	31.2	1.19	29579.	0.485	1679238.	1.76	20.961	9916196.	0.30
24	28.8	3.36	83518.	0.450	59222067.	0.14	17.861	18315108.	0.46
22	26.4	8.72	216749.	0.415	**********	0.00	15.008	39438151.	0.55
20	24.0	17.84	443440.	0.379	**********	0.00	12.403	114827883.	0.39
18	21.6	39.58	983820.	0.344	**********	0.00	10.047	875931539.	0.11
16	19.2	65.30	1623129.	0.308	**********	0.00	7.938	**********	0.00
14	16.8	99.77	2479933.	0.271	**********	0.00	6.078	**********	0.00

TAL	*LSF	Axle/ 1000	Expected Reps	Stress Ratio	Allowable Reps	Fatigue Consump	Power	Allowable Reps	Erosion
68	81.6	0.04	994.	0.589	42572.	2.34	57.362	438348.	0.23
64	76.8	0.10	2486.	0.556	105412.	2.36	50.612	619676.	0.40
60	72.0	0.59	14665.	0.523	289476.	5.07	44.659	899615.	1.63
56	67.2	1.94	48222.	0.490	1257301.	3.84	38.903	1349086.	3.57
52	62.4	4.47	111109.	0.457	19799648.	0.56	33.544	2107233.	5.27
48	57.6	11.70	290821.	0.424	**********	0.00	28.582	3470897.	8.38
44	52.8	31.49	782731.	0.391	**********	0.00	24.017	6149034.	12.73
40	48.0	100.56	2499570.	0.357	**********	0.00	19.849	12132683.	20.60
36	43.2	203.53	5059043.	0.324	**********	0.00	16.077	28646271.	17.66
32	38.4	276.37	6869591.	0.290	**********	0.00	12.703	98346178.	6.99

Total Fatigue Used = 40.79   Erosion Damage = 79.93

10.0 Inch Thickness Inadequate, Fatigue Used= 134.28   Erosion Damage = 125.43

PCAPAV(TM) 1.10
Proprietary Software of PORTLAND CEMENT ASSOCIATION

Project: Trial8
Engineer: J. Bervell
Input Data:
Subgrade / Subbase K 150.0 PCI
Modulus of Rupture MR 600.0 PSI
Avg. Daily Truck Traffic (2 way) ADTT 3405.00
Design Life 40 years
Doweled Joints
Concrete Shoulders
Load Safety Factor 1.2
Estimated Pavement Thickness 10.5 IN

A X L E L O A D S
Axles per 1000 Trucks

Single		Tandem	
32	0.20	68	0.04
30	0.36	64	0.10
28	0.54	60	0.59
26	1.19	56	1.94
24	3.36	52	4.47
22	8.72	48	11.70
20	17.84	44	31.49
18	39.58	40	100.56
16	65.30	36	203.53
14	99.77	32	276.37

Design Thickness =9.0 Inches

Load Repetitions ---Fatigue Analysis----- ----Erosion Analysis---

SAL	*LSF	Axle/ 1000	Expected Reps	Stress Ratio	Allowable Reps	Fatigue Consump	Power	Allowable Reps	Erosion
32	38.4	0.20	4971.	0.601	30256.	16.43	19.159	886891.	0.56
30	36.0	0.36	8948.	0.565	80901.	11.06	16.839	1495529.	0.60
28	33.6	0.54	13423.	0.530	229119.	5.86	14.669	2819900.	0.48
26	31.2	1.19	29579.	0.494	1014638.	2.92	12.648	6464512.	0.46
24	28.8	3.36	83518.	0.458	17196202.	0.49	10.777	23191771.	0.36
22	26.4	8.72	216749.	0.422	**********	0.00	9.056	**********	0.00
20	24.0	17.84	443440.	0.386	**********	0.00	7.484	**********	0.00
18	21.6	39.58	983820.	0.350	**********	0.00	6.062	**********	0.00
16	19.2	65.30	1623129.	0.313	**********	0.00	4.790	**********	0.00
14	16.8	99.77	2479933.	0.276	**********	0.00	3.667	**********	0.00

TAL	*LSF	Axle/ 1000	Expected Reps	Stress Ratio	Allowable Reps	Fatigue Consump	Power	Allowable Reps	Erosion
68	81.6	0.04	994.	0.558	98309.	1.01	30.435	181842.	0.55
64	76.8	0.10	2486.	0.528	248854.	1.00	26.960	267623.	0.93
60	72.0	0.59	14665.	0.496	906224.	1.62	23.695	411356.	3.57
56	67.2	1.94	48222.	0.465	80[illegible]361.	0.60	20.641	670292.	7.19
52	62.4	4.47	111109.	0.434	**********	0.00	17.798	1187315.	9.36
48	57.6	11.70	290821.	0.403	**********	0.00	15.165	2397831.	12.13
44	52.8	31.49	782731.	0.371	**********	0.00	12.743	6166537.	12.69
40	48.0	100.56	24995[illegible]0.	0.339	**********	0.00	10.531	29879832.	8.37
36	43.2	203.53	5059043.	0.307	**********	0.00	8.530	**********	0.00
32	38.4	276.37	6869591.	0.275	**********	0.00	6.740	**********	0.00

Total Fatigue Used = 40.98 Erosion Damage = 57.23

8.5 Inch Thickness Inadequate, Fatigue Used= 165.94 Erosion Damage = 112.03