6th International Symposium on
Heavy Vehicle Weights and Dimensions
Saskatoon, Saskatchewan, Canada June 18 - 22, 2000

# COMPOSITION OF TRUCK TRAFFIC IN PAVEMENT TYPE SELECTION OF LOW VOLUME ROAD IN SASKATCHEWAN

Guoxin Liu and Satish Sharma
Faculty of Engineering,
University of Regina,
Saskatchewan, Canada

Allan Widger
Engineering Service,
Sask. Highways & Transportation,
Saskatchewan, Canada

## ABSTRACT

Pavements for low volume highways have thin structures, which are at higher risk due to truck loading variations. Many agencies design their low volume pavements by using approaches that are simplified from the procedures used for high volume pavements. Pavement design procedures often include the selection of a pavement type, which is usually determined according to engineering and economic analysis. A structure is designed based on the agency's established policy for the pavement type. This procedure makes the pavement type selection an important step in pavement design. It is a common practice in highway agencies to select a pavement type based mainly on traffic volume. However, traffic stream may contain different truck percentages and truck compositions. The current trend of more and larger trucks on Saskatchewan highways warrants a closer examination of traffic loading considerations in the design of low volume pavement. This paper analyzes 48-hour vehicle classification counts from Saskatchewan highways. Spatial patterns of truck traffic show that high and low truck percentages are clustered in separate areas. Also, high percentages of small truck are mainly clustered on highways with low truck percentages. This demonstrates the need for pavement type to be more responsive to the actual truck type using the pavement. Regression analysis is performed on vehicle classification data and ADT (average daily traffic), TP (truck percentage), and CM (content of the largest multi-trailer truck, type 13 in FHWA classification scheme) are identified as significant parameters correlated to equivalent single axle load (ESAL). The paper introduces a traffic-loading index (TLI) and a procedure involving a plot of TLI and ADT and dividing traffic level into several design requirement zones for the selection of pavement types. Case studies show that proper pavement type selection under various traffic conditions can be achieved by using the proposed procedure.

# 1.0 INTRODUCTION

Pavements for low volume highways have thin structures, which are at higher risk due to truck loading variations compared to thick structure pavements. Many agencies design their low volume pavements by using approaches that are simplified from the procedures used for high traffic volume highways. The selection of a pavement type is an important step for low volume pavement design. It is a common practice in highway agencies to select a pavement type based mainly on traffic volume. This is inadequate considering the fact that traffic stream may contain very different proportion of trucks and very different truck composition. Different proportions of truck traffic and various truck type compositions will have different damaging impacts on these thin structures. The selection of secondary highway pavements should be closely related to traffic loading.

It is a fact that there is less extensive traffic counting effort on low volume roads and thus less accurate traffic information is expected. This means that the load-sensitive thin structures of low volume pavements will experience more uncertain traffic loading during service. Considering these factors and bearing in mind the fact that most highway sections have low volume pavement structures in Saskatchewan, it is necessary to study traffic loading analysis in detail to get a rational method for determination of low volume pavement design. The objectives of this study are to review traffic analysis practices in design of low volume pavements in different agencies and to propose a method for traffic loading analysis in pavement geometric and structural type selection and estimate the possible accuracy ranges and effects of the method.

# 2.0 REVIEW OF TRAFFIC LOADING CONSIDERATIONS IN LOW VOLUME PAVEMENT DESIGN

Highway agencies often use different design practices for standard pavement and low volume pavement designs mainly due to financial constraints. However, design of low volume pavements should involve the same principles used for primary pavements except that traffic volumes are low and frequently the distribution of vehicle type is considerably different (AASHTO, 1986). Design procedures in different highway agencies use different approaches for traffic loading considerations in low volume pavement design. For practical purpose of construction standards and management, pavement design procedures often include a pavement type selection process. A pavement type is usually determined according to engineering and economic analysis. Then a pavement structure is designed based on the agency's established policy for the determined pavement type. This procedure makes the pavement type selection a very important step for low volume road design. The process of selecting the proper pavement type is complex and hard to define. All engineering factors must be properly and carefully analyzed. Traffic is considered as one of the principal factor in the pavement type selection process (AASHTO, 1986). It is a common practice in highway agencies to select a pavement type based mainly on traffic volume.

In AASHTO design guide (AASHTO, 1986), no detailed procedure is provided for pavement type selection. Instead, a flow chart and a list of factors are provided for consideration. The low volume road design procedure is basically the same as those for standard pavement design except that level of reliability recommended is 50% because of their low usage and the associated acceptable level of risk. Asphalt Institute recommends the minimum thickness of asphalt concrete based on ESAL level.

Manitoba design procedure (Manitoba Highways, 1996) uses an empirical equation to calculate the equivalent base course design thickness (EBD). The loading factor and traffic factors that are considered in the process to obtain EBD are the same for all low volume highways. The selection of low volume pavements is based on the level of projected AADT (annual average daily traffic). ESALs are used to determine the thickness of asphalt surfacing for each highway class.

Idaho state (Erickson, 1975) uses percentages of two-axle and five-axle vehicles to develop a traffic index, which is directly used in a formula together with subgrade's R-value to calculate the equivalent gravel thickness. In Virginia (Virginia DOT, 1996), a design ADT (average daily traffic) is calculated by considering growth rate and percentages of trucks. Each truck above 5% level is considered equal to 20 equivalent present traffic (EPT) of design ADT. Thickness index is then determined from a nomograph by projecting a straight line from the soil support value through the design ADT to intersect the required thickness index scale.

In Saskatchewan, low volume pavements may use one of following structure and geometric standards: Pavement A (designed staged structure), Pavement C (designed granular structure with a double seal), and designated Thin Membrane Surface (TMS, soft asphalt mat on top of a compacted subgrade) (Saskatchewan Highways, 1981). AADT is used as a guide to select a specific pavement type and corresponding design standards. The AADT is adjusted to a higher level according to the highway capacity analysis if the truck percentage is higher than the normal range of 10% to 12%. However, the type of trucks is not considered. For example, 700 > AADT > 150 is the range for Pavement C or TMS structure, and Pavement A will be needed for AADT > 700. Once a pavement type is determined, ESAL will then be calculated for thickness design of Pavement A or C.

The traffic volume (AADT) seems to be more important in the selection of a pavement type in most agencies. Although some design procedures also require calculating EASL for detailed pavement design, the established policy for a particular type of pavement may prevent a complete design process. For example, if the pavement type C is determined for a section of low volume pavement design using Saskatchewan method, the maximum thickness of base course is designated by the department's policy (Saskatchewan Highways, 1981) regardless of the design curve requirement from actual ESAL calculation. This means that traffic volume actually is used to determine the pavement type and to some extent a part of the structure as well. It is possible that using only traffic volume in pavement type selection for low volume highways can underestimate actual traffic loading and their impacts on pavements. The current trend of more and heavier trucks on Saskatchewan highway system due to the abandonment of railroad branches and the consolidation of grain handling capacity warrants a closer examination of traffic loading considerations in the design of low traffic volume pavement.

Another factor that should be discussed is the quality of traffic data used in the analysis of low volume pavement design. Traffic count programs on low volume roads are less extensive and traffic information available for these roads is normally short counts or adjusted short counts (for example, ADT and adjusted AADT). If traffic is relatively uniform temporally and spatially, these procedures should provide satisfactory result for the annual average. However, traffic volume and vehicle type distributions are very different temporally and spatially on low volume highways. Traffic data from the short count is not reliable, especially for truck traffic information from low volume roads. Thus the selection of a pavement type and pavement design based on short traffic counts require significant engineering judgement. The experience from many North American jurisdictions is that the decline in level of railway services and changing traffic modes have resulted in a considerable underestimation of commercial traffic (AASHTO, 1986).

Each type of pavement structure has its own service quality, cost and life expectancy and thus a proper traffic level to serve. Since the large network of low volume highways will continue to exist for a long time, appropriate procedure to determine a pavement type using traffic data should be part of an integral pavement strategy.

## 3.0 TRUCK TRAFFIC VARIATIONS

Short period counts are widely used to sample traffic especially on low volume highways. There is a great deal of uncertainty in the short count result due to the inherent traffic temporal variations, which include random daily variations and some patterned seasonal variations. This uncertainty is normally greater for low volume highways because small volume changes mean large percentage variations. Short counts of traffic volume can be corrected to some extent by correction factors from traffic pattern groups to derive an AADT. However, there is no adjustment mechanism for the variations of truck volume, truck type and axle weight in the existing traffic monitoring systems [Stamatiadis, 1997].

One study in Saskatchewan (Liu, 1997) showed that truck traffic could be very different on low volume highway sections even for the same AADT. The same study also showed that traffic and truck traffic had very different patterns of temporal variations. It was found that truck percentages on the secondary highways could vary from 2% to more than 50%. Using GIS techniques to print truck traffic information on Saskatchewan highway maps by colors, the variations of truck traffic showed some evident spatial patterns on the maps relating the layout of the highway network and local economic situations (Liu, 1997). It was found that the low volume highway sections with high and low truck percentages are clustered in separate areas. It was also found that higher percentages of small trucks (2-axles single unit) were mainly clustered on highway sections with low truck percentages. These highway sections are mainly in agricultural areas. Higher percentage of large trucks (type 13 in FHWA vehicle classification scheme, multi trailer trucks with 7 or more axles) were clustered on highway sections with higher truck percentages. These highway sections are mainly in areas with oil industry activities. For the same AADT level, the highway sections with higher truck percentage and more large trucks on average can have more than double the ESAL for highway sections with low truck traffic level. With the continued railroad abandonment, grain handling facility consolidation and increased truck size, the truck type composition on low volume roads will likely shift to more larger trucks.

A recent truck weight survey of more than 1000 trucks on Saskatchewan highways shows that average truck weight for the largest truck type can be 10 times the weight of the smallest truck type. The number of ESAL of the largest type of truck can be 7 times higher than the smallest type of truck. There are also evidences to show that the volume of larger trucks grows at a much faster rate than small trucks on many Saskatchewan highways (Lee & Lau, 2000). These reality makes it easy to under-design or over-design low volume pavements without detailed traffic loading analysis. The highways having more trucks and large trucks should have better structures to handle the traffic loading.

## 4.0 PROPOSED PROCEDURE FOR PAVEMENT TYPE SELECTION FOR LOW VOLUME ROADS

There seems to be a general trend towards a more precise design and performance prediction for a pavement due to financial constraint of highway agencies and vigorous pavement management programs. These require detailed traffic loading analysis in the whole design process. A survey of engineers was conducted in Saskatchewan highway department regarding the traffic information need in the design process of low volume pavements (Liu, 1998). Almost all engineers considered AADT and vehicle classification as essential information for low volume pavement design. The survey result demonstrate a good consensus among engineers that more and better traffic and loading information should be incorporated in the process of determining low volume pavement structure.

Traffic loading estimates are largely dependent on truck traffic data, which often comes from vehicle classification counts. In North America, the FHWA's (Federal Highway Administration) thirteen-group scheme is widely used. The scheme categorizes motor vehicles into thirteen types according to vehicle size and axle configurations. There are nine types of trucks categorized by the scheme.

A large number of 48-hour vehicle classification counts from low volume highways in Saskatchewan were analyzed (Liu, 1998). ADT, TP (truck percentage) and percentage of each truck type were used to calculate traffic loading ESAL (equivalent single axle load) per day assuming all truck axles were loaded to 80% of their legal weight limits (historical data showed 68% to 90% of weight limits for all trucks on average). The backward regression analysis was performed on the classification data to identify significant parameters correlated to equivalent single axle load (ESAL). ADT (average daily traffic), TP (truck percentage), and CM (content of the largest multi-trailer truck, the percentage of truck type 13 in FHWA vehicle classification scheme) were identified as significant traffic parameters correlated to ESAL per day. The following equation (with $R^2 = 0.82$) resulted from the regression analysis:

(Eq.1) $$ESAL/day = -118.82 + 0.15ADT + 1031.95TP + 81.56CM$$

It is recognized that highway agencies need some policy thresholds to determine pavement type and set pavement design standards for better planning and management. Such thresholds for low volume pavements are particularly useful because of the potential to have simplified design and construction process for simple structures. Based on the relationship in (Eq.1) and assuming an annual growth rate of 1.5% for all traffic on highways (historical data showed 1.4% to 1.6% annual growth rate), the traffic-loading index TLI is introduced as following:

(Eq.2) $$TLI = 0.0296ESAL^{0.455}$$

Where, ESAL is the five-year accumulative ESAL for a highway section. The traffic loading index TLI is related to ADT and truck traffic through the ESAL on highway sections. A procedure involving a plot of TLI and ADT is proposed for the selection process of low volume pavement type. The procedure considers both total traffic and the type of trucks on the road. Highway engineers' opinion on the level of traffic volume and truck traffic is also used to divide traffic conditions into several design requirement zones.

The traffic-loading index TLI is related to traffic loading ESAL. It also increases with ADT linearly as showed in Fig. 1. In Fig. 1, all calculated TLI values are plotted against surveyed ADTs on secondary highways in Saskatchewan. Three lines separate all data points into four different traffic level zones. The three lines represent the upper, middle and lower limits for the highest, intermediate and lowest traffic levels on low volume highways in Saskatchewan. Obviously, the zone having higher traffic level require better pavement type. The lines were calculated through critical values for ADT, TP and CM obtained by interviewing experienced pavement design engineers in the highway department. These values can be seen from Table 1. Each pair of points represents an equivalent traffic level considering both total traffic volume and truck traffic. The equations for the three dividing lines are:

(Eq.3) $$TLI_{upper} = -0.03ADT + 15.28$$

(Eq.4) $$TLI_{middle} = -0.02ADT + 19.58$$

(Eq.5) $$TLI_{lower} = -0.01ADT + 21.99$$

The four traffic level zones represent ranges of traffic conditions in which different structures of low volume pavements should be used. Zone-1 represents the most intensive traffic (high ADT and high TLI) on low volume highways, thus the best (geometric and structural) low volume pavement should be provided. Zone-2 and Zone-3 have medium traffic intensity and should be provided with intermediate type low volume pavement. The lowest standard of low volume pavements will be used for Zone-4 that has the lowest traffic intensity. Fig. 1 shows that a low ADT level with a high TLI value is possible to be treated the same way as a high ADT level with a low TLI value. This is because a low traffic volume with high truck traffic requires a pavement structure for the truck loading while a high traffic volume with low truck traffic may require the same pavement since the higher traffic volume will have lower tolerance for any type of failures. The number of zones and precise positions of dividing lines are expected to vary according to input from the management and engineers.

## 5.0 CASE STUDIES

The following typical scenarios based on actual data on low volume Saskatchewan highways were considered in this study.

**Scenario 1** Two low volume highway sections have the same traffic volume (*ADT*) but very different truck percentages (*TP*).

For example, in Table 2, the two highway sections selected from the sample data have the same *ADT*. The *CM* value for the two sections are also very similar. However, the control section *CS47-03* has a higher truck percentage (TP), which results in a higher ESAL and *TLI* value. Control section *CS47-03* is classified into traffic level Zone-2. The other control section (*CS8-08*) has much less truck traffic, which results in a lower *TLI* value. *CS8-08* falls into a lower traffic level zone Zone-3.

The highway section with more truck traffic should be classified into a higher traffic level and provided with a better pavement structural standard than the section with less truck traffic if they have the same *ADT*. It is clear that the *TLI* has reflected the truck traffic intensity for the two highway sections.

**Scenario 2** Two low volume highway sections have the same *ESAL* level but different traffic volume (*ADT*).

For example, in Table 3, the highway section (*CS26-01*) with a higher *ADT* is classified into traffic level Zone-2 while the other highway section (*CS3-03*) with a lower *ADT* is classified into a lower traffic level Zone (Zone-3). This result is derived despite the two highway sections having the same level of traffic loading in terms of *ESALs*. It is important to note that the purpose of low volume highway is not just to provide adequate structural strength for traffic loading but to provide accessibility with reasonable riding comfort to the rural population. Road sections with more traffic volume should be provided with better pavement in terms of geometric standards than sections with less traffic volume even though they carry the same *ESALs*. The result of this example indicates that the method clearly reflects the difference in traffic volume even though the *ESAL* is the same.

**Scenario 3** Two low volume highway sections have the same level of *ADT* and *TP* but different percentages of larger trucks (*CM*).

For example, in Table 4, the highway section *CS55-16* with a much higher *CM* results in a higher *TLI* value and is classified into traffic level Zone-1. While the other highway section (*CS32-01*) with a lower *CM* has a lower *TLI* value and falls in a lower traffic level zone (Zone-2). Obviously, if all other conditions are the same, the highway section with more large truck traffic (truck type 13) should be provided with better pavement than the section with less large truck traffic. It is clear from this scenario that the proposed method can also reflect differences in the relative intensity of large truck traffic.

The results of these scenario analyses demonstrate that the proposed method can provide reasonable results under a variety of traffic conditions. These above scenario analyses also demonstrate the advantage of using the *TLI* vs. *ADT* plot to determine low volume pavements: it considers both rural population accessibility, public tolerance to pavement conditions, and traffic loading conditions while *ESAL* only deal with truck traffic loading. It is also relatively easy to get the traffic information required to calculate *TLI* and to plot *ADT* vs. *TLI* when making a pavement type selection. In the detailed pavement design, *ESALs* are then calculated to design structure thickness. This approach prevents an over-emphasis on *ADT* or *ESAL* in pavement type selection and provides a more clear procedure for decision making.

## 6.0 ACCURACY OF TRAFFIC LOADING ANALYSIS AND ITS IMPACTS

There is a great deal of uncertainty in traffic loading analysis. Such uncertainty is even greater for the low volume highways because unadjusted short count data are normally involved. The accuracy of traffic counts and impacts of such accuracy on traffic loading analysis and pavement design therefore should be analyzed to give engineers more complete information for determining pavement structures.

It is impossible to estimate errors of 48-hour classification counts from the secondary highway sites because there is no continuous count to provide the true values. In this study, continuous counts from four automatic vehicle classifier (AVC) sites on the primary highways are analyzed to provide approximations. Table 5 shows the mean errors, their 95% confidence intervals for the mean errors (mean ± 95% TI), and the tolerance intervals containing 85% of error population at 95% confidence level (mean ± TI85) for 48-hour counts of ADT, TP and CM from four AVC sites on Saskatchewan highways. The samples are taken from the weekdays in months of April, May, June, September and October since the short counts are conducted mainly during these months. The mean errors of 48-hour count for ADT are relatively small. For the first three sites that are located on long distance highway routes (either cross province or cross-country) the mean errors of the three parameters are less than 20%. However, the errors for ADT and TP are much higher for the site that mainly serves local traffic (Yorkton). The mean errors for ADT is 25% and the mean errors for TP is 31.3% this route. It is expected that the traffic on low volume highways is similar to local service traffic conditions (Yorkton), and thus, the mean errors of 48-hour counts may range from 25% for ADT, 35% for TP and 17% for CM if the time of counts is in the same months. Errors from individual counts can be much higher than these values as demonstrated by the large values of TI85 for the local traffic service Yorkton site. Using these error ranges to calculate TLI and compare with traffic level zones in Fig. 1, TLI may change up to 30%, and up to 60% to 80% sites may have been upgraded one traffic level zone. Only 3% to 5% of sites may have been upgraded two traffic level zones. Design engineers should be aware of this information and give proper flexibility in standard application.

## 7.0 CONCLUDING REMARKS

Pavement type selection should be recognized as an important step for low volume pavement design. It is not appropriate to use only traffic volume in pavement type selection process. Truck percentage and truck type compositions on low volume highways are considerably different from section to section. This reality demonstrates a need for low volume pavement type selection to take both truck traffic and total traffic into consideration. A traffic-loading index based on ESAL calculation is introduced. The index TLI and ADT plot can be used to identify a proper traffic level for a pavement type to be applied. Several real case scenarios are examined and the proposed procedure for pavement type selection provides reasonable results. The accuracy analysis indicates that 48-hour AVC counts may have relatively large errors for ADT, TP and CM. These errors will have impacts on traffic level zones. It is recognized that subgrade conditions also play an important role in low volume pavement design process. It is believed that this traffic information together with subgrade conditions can provide a better method in the design process for low volume highway pavements.

## ACKNOWLEDGMENT

The authors acknowledge the financial and traffic data assistance from the Saskatchewan Highways & Transportation. Mr. L. Lee had performed parts of error calculations.

## REFERENCES

AASHTO: AASHTO guide for design of pavement structures, Washington, D.C., American Association of State Highway and Transportation Officials, 1986

Erickson, L. F.: Low volume road pavements, Transportation Research Board, Special report 160, National Research Council, Washington DC, 1975, pp204-209

Lee, S. and Lau, R.: Commercial vehicles on trans-provincial and local highways in Saskatchewan, engineering student project, University of Regina. April, 2000.
Liu, G. X. and Lee L.: Traffic loading analysis for Saskatchewan secondary highways and its accuracy. Research report to Saskatchewan Highways and Transportation, Canada, November 1998
Liu, G. X., Anderson, T. and Lee, L. P.: An evaluation of heavy vehicle traffic on Sask. secondary weight highway system, Proc. of 1997 CSCE conference, pp283-292.
Manitoba Highways & Transportation: Pavement design & management manual, Manitoba, December 1996
Saskatchewan Highways & Transportation: Saskatchewan Surfacing Manual, 1981
Stamatiadis N. and Allen D.: Seasonal factors using vehicle classification data. TRB 76 Annual Meeting, Paper No. 970094. Washington DC, Jan. 12-16, 1997
Virginia Department of Transportation: pavement design guide for subdivision and secondary roads in Virginia, USA, January 1996

**Table 1 Critical values of each traffic parameter and *TLI* for different levels of traffic intensity**

| Critical Points | *ADT* | *TP* | *CM* | *TLI* |
|---|---|---|---|---|
| Pair 1 | 150 | 30% | 25% | 12.20 |
| Pair 1 | 300 | 10% | 10% | 5.54 |
| Pair 2 | 500 | 22% | 25% | 11.35 |
| Pair 2 | 700 | 10% | 10% | 7.83 |
| Pair 3 | 900 | 19% | 25% | 12.57 |
| Pair 3 | 1200 | 7% | 2% | 9.43 |

Table 2 Highway sections with the same *ADT* but different truck traffic

| Control Section | *ADT* | Truck % (*TP*) | Truck Type13* (*CM*) | *TLI* | *ESAL* | Zone |
|---|---|---|---|---|---|---|
| CS8-08 | 541 | 10.18% | 5.5% | 6.87 | 76,560 | 3 |
| CS47-03 | 541 | 28.18% | 4.93% | 13.29 | 211,635 | 2 |

* Truck type 13 in FHWA classification scheme, multi-trailer trucks with 7 or more axles.

Table 3 Highway sections with the same *ESAL* level but different ADT

| Control Section | *ADT* | Truck % (*TP*) | Truck Type13 (*CM*) | *TLI* | *ESAL* | Zone |
|---|---|---|---|---|---|---|
| CS3-03 | 505 | 12.50% | 24.00% | 7.96 | **97,886** | 3 |
| CS26-01 | 1021 | 7.20% | 6.11% | 8.58 | **97,798** | 2 |

Table 4 Highway sections with the same *ADT* and *TP*, different *CM*

| Control Section | *ADT* | Truck % (*TP*) | Truck Type13 (*CM*) | *TLI* | *ESAL* | Zone |
|---|---|---|---|---|---|---|
| CS32-01 | 1105 | 10.04% | 6.77% | 10.09 | 147,184 | 2 |
| CS55-16 | 1081 | 11.00% | 36.36% | 11.04 | 206,034 | 1 |

Table 5 Errors for 48 hour counts at four AVC sites

| AVC sites | Indian Head | Lloydminster | Estevan | Yorkton |
|---|---|---|---|---|
| | | **ADT** | | |
| **Mean** | 13.70% | 11.40% | 12.92% | 25.07% |
| **95%TI** | 2.56% | 3.50% | 3.28% | 2.93% |
| **TI85** | 20.92% | 19.01% | 17.60% | 24.43% |
| | | **TP** | | |
| **Mean** | 19.45% | 14.06% | 17.45% | 31.33% |
| **95%TI** | 3.39% | 2.43% | 4.65% | 3.86% |
| **TI85** | 27.63% | 13.20% | 24.93% | 32.19% |
| | | **CM** | | |
| **Mean** | 15.49% | 7.20% | 19.75% | 17.80% |
| **95%TI** | 2.80% | 1.56% | 5.86% | 2.50% |
| **TI85** | 22.85% | 8.48% | 31.39% | 20.83% |

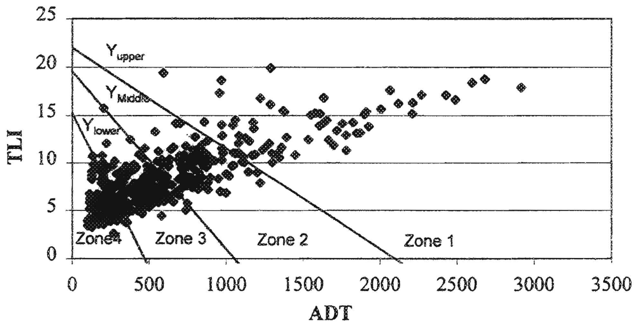


Figure 1 Traffic level zones for low volume pavement selection