CLUSTER ANALYSIS

Eight WIM sites in NM from LTPP database were selected and traffic data were clustered by groups respectively. Cluster analysis is a multivariate technique to estimate natural groupings among various attributes. Hierarchical clustering method was used in this study which cluster groups' data over a variety of scales by creating a cluster tree or dendrogram. The tree is not a single set of clusters but rather a multilevel hierarchy where clusters at one level are joined as clusters at the next level. The agglomerative strategy was used. For this example, objects are the 8 LTPP WIM sites and attributes are the values in the 40 load bins of the normalized axle load distribution. These values are percentages and did not need to be standardized because they were all of similar magnitude. First, the Euclidean distance d_{ij} between attributes for each pair of objects are obtained. If there were only two attributes i and j and they were plotted in a Cartesian coordinate system, Euclidean distance would be the linear distance between the two objects defined on this plot by their coordinates. For more than two attributes, a similar definition would apply, the difference being that this would be multidimensional plot (40-dimensional, in this case) (Papagiannakis et al. 2006). Table 2 shows the Euclidean matrix for the annual distribution of single axle loads in NM LTPP sites.

Table 2. Euclidean Distance Matrix: Annual Distributions of Single Axle Loads.

Site	0100	0500	0900	1112	2007	2118	3010
0100							
0500	0.118						
0900	0.233	0.182					
1112	0.172	0.132	0.124				
2007	0.171	0.116	0.274	0.236			
2118	0.153	0.165	0.261	0.224	0.213		
3010	0.196	0.151	0.121	0.036	0.256	0.238	
6033	0.343	0.346	0.476	0.447	0.296	0.258	0.461

After finding the Euclidean distance, it grouped the objects into a binary, hierarchical cluster tree and where to cut the hierarchical tree into clusters was determined. The final result is shown in Figure 1.

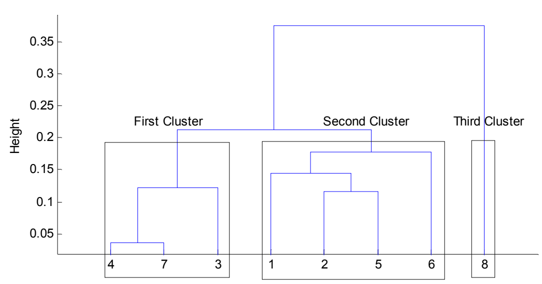
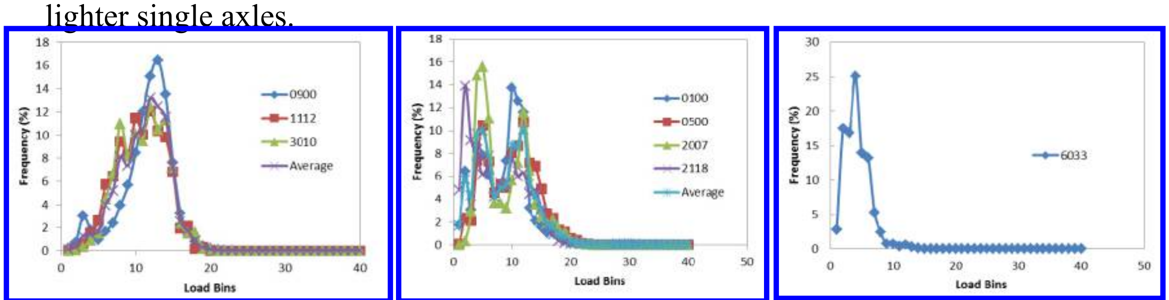


FIG. 1. Clustering tree: annual distributions of single axle loads, (1=0100, 2=0500, 3=0900, 4=1112, 5=2007, 6=2118, 7=3010, and 8=6033).

Cluster Analysis Results

Figure 2 show the frequency distributions of single axle loads for the identified three cluster groups of sites. These patterns reflect the relative proportion of single axles that are empty or carry light commodities versus those that are loaded with heavy commodities. Hence: Cluster 1: dominance of heavier single axles; Cluster 2: roughly equal frequency of light and heavy singles; and Cluster 3: dominance of lighter single axles.



a) First cluster b) Second cluster c) Third cluster

FIG. 2. Distributions of single axle loads for three identified cluster groups.

MEPDG ANALYSIS

Design Inputs

For the MEPDG analysis design inputs are selected based on the current practice in NM. A three layer pavement with asphalt concrete (AC) as the top layer is selected based on the current practice of NMDOT. Table 3 describes the inputs information for MEPDG.

Table 3. MEPDG inputs selected for the analysis

General inputs		**Structural parameters**	
Parameter	Values	Layers	Properties
Design life (years)	20	AC	Thickness: 6 in Air Void: 5% Binder Content: 10% Binder Grade: PG 70-22 Total unit weight: 175 pcf
Climate data	NMDOT 4.icm		
Initial two-way AADTT	3000		
Number of lanes per direction	2	Base	Thickness: 12 in Material: Crushed Stone Modulus: 30000 psi
Percent of trucks in design lane	95%		
Percent of trucks in design direction	50%	Subgrade	Material: A-1-b Modulus: 26500 psi
Operational speed (mph)	70		

In this study the effect of different traffic inputs on pavement performance were evaluated. Also the performance parameters for clusters were compared with the MEPDG default value. Table 4 described the different traffic variables considered in this study.

Table 4. Summary of Traffic variables used in this study.

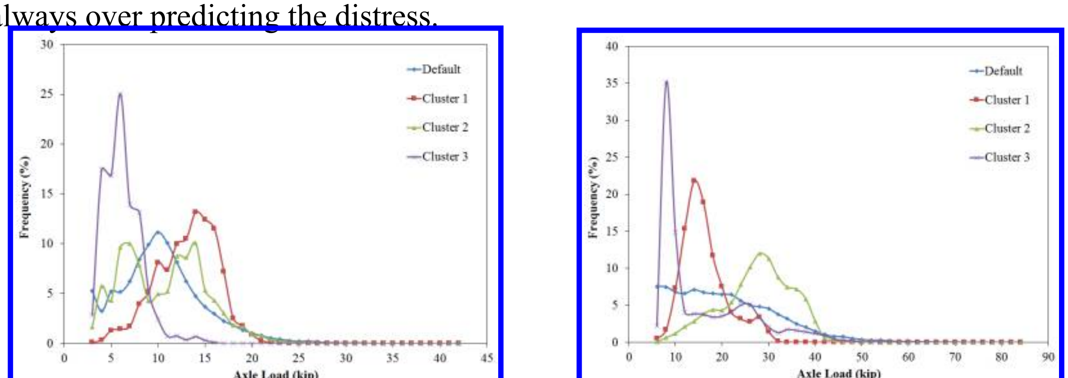
Traffic Inputs		Recommended traffic input level
Axle Load Distribution Factors	Single axle load spectra	Default and Cluster (1, 2 and 3)
	Tandem axle load spectra	Default and Cluster (1, 2 and 3)
	Tridem axle load spectra	Default and Cluster (1, 2 and 3)
	Quad axle load spectra	Default and Cluster (1, 2 and 3)

MEPDG PERFORMANCE PREDICTIONS

The MEPDG analysis is performed by running the MEPDG software, based on above characteristics and the traffic variables discussed above. In this study total two variables are considered: Single axle load distribution and Tandem axle load distribution. The cluster analysis helps grouping the traffic sites into clusters, based on similarity of data for a given parameter. MEPDG runs were performed with the suggested average parameters obtained for each cluster. In the first run, all the traffic variables are set as the MEPDG default. The predicted performances (outputs) for this run are used as the base for the sensitivity analysis. For the next MEPDG runs, each time, one of the four variables is changed from the MEPDG default value. MEPDG predicted distresses for all variables are discussed in the following sections.

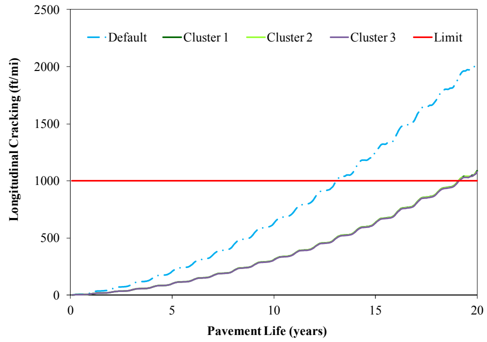
Single Axle Load Distribution

Figure 3(a) shows the load spectrum of single axle for the default value and the cluster values. As from the load spectrum it can be seen that cluster 3 is mostly deviated from the default value. Other clusters have similar distribution as default value. Figure 4 shows all type of predicted distress values from MEPDG. It shows that longitudinal cracking, alligator cracking and rutting are deviated from the default MEPDG output with the change of single axle load distribution. Change in single axle load distribution affect the IRI value compared to the other variables discussed above. From all the predicted distresses it can be seen that MEPDG default value is always over predicting the distress.

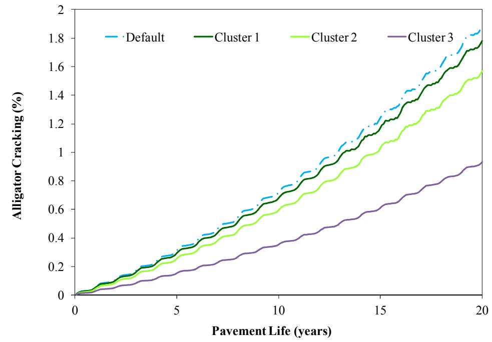


(a) Single axle (b) Tandem axle

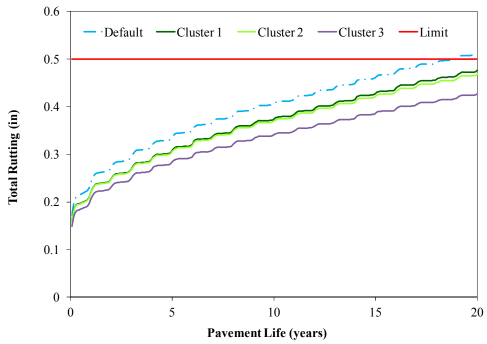
Fig. 3. Axle load distribution.



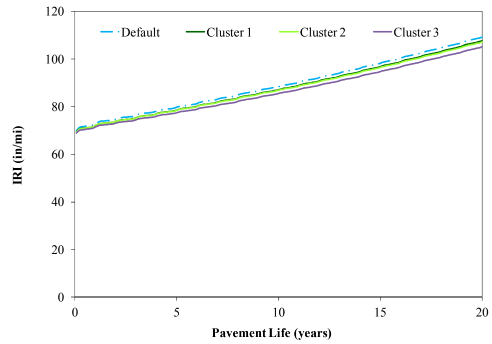
a) Longitudinal Cracking



b) Alligator Cracking



c) Total Rutting

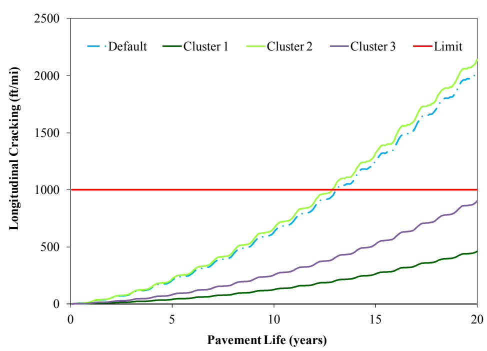


d) IRI

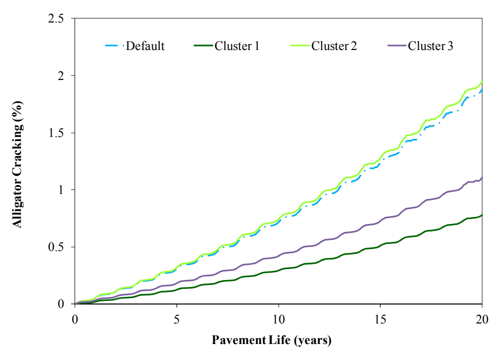
Fig. 4. Predicted distresses for different Single axle load distribution inputs.

Tandem Axle Load Distribution

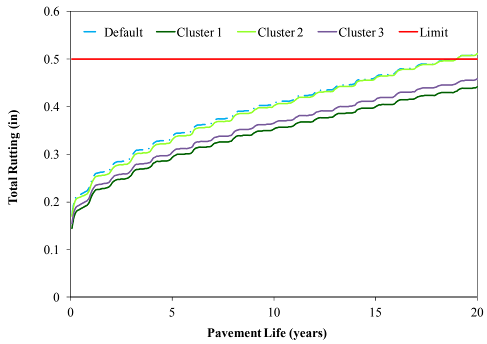
Figure 3(b) shows the load spectrum of tandem axle for the default value and the cluster values. As from the load spectrum it can be seen that all the clusters have different pattern compared to the default value. Cluster 3 has the highest frequency over the lower load, whereas default value has the lowest frequency all over the load bins. Figure 5 shows all type of predicted distress values from MEPDG. It shows that longitudinal cracking, alligator cracking and rutting are deviated from the default MEPDG output for different tandem axle load distribution. Change in tandem axle load distribution affect the IRI value compared to the other variables discussed above. In the Fig. cluster 2 and default MEPDG value showed similar pattern, whereas cluster 1 and 3 is more deviated from the default.



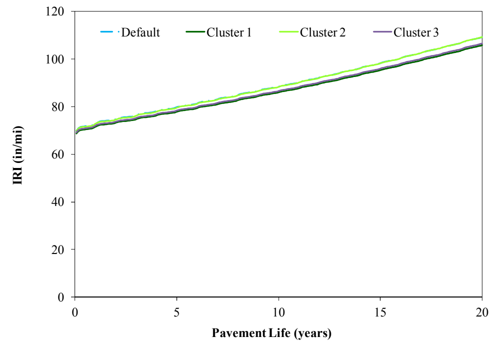
a) Longitudinal Cracking



b) Alligator Cracking



c) Total Rutting

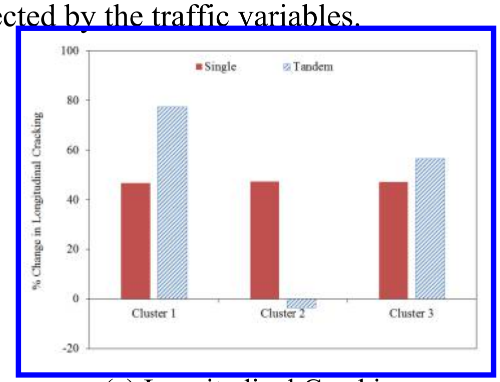


d) IRI

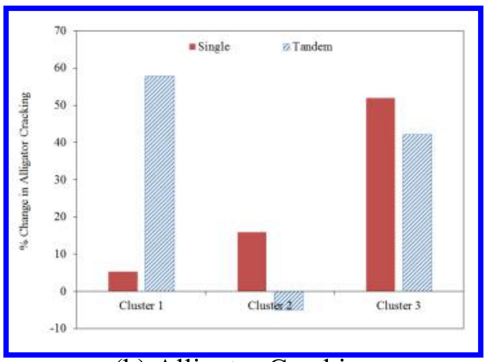
Fig. 5. Predicted distresses for different Tandem axle load distribution inputs.

The Effect of the Variability of Traffic Parameters on the Performance

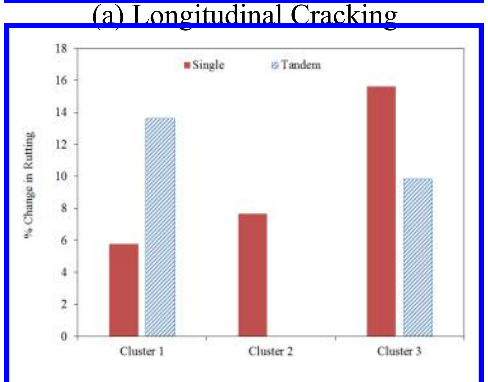
Figure 6 shows the effect of clustering and traffic variable on the predicted distresses. The percent change in the distress are calculated from the difference between the cluster value and default value. Only the maximum predicted distress values are considered to find out the change due to traffic variables and clustering. Figure 6(a) shows that longitudinal cracking is mostly influenced by the tandem axle load distribution. Figure 6 (b) shows that alligator cracking is mostly influenced by the single and tandem axle load distribution. Figure 6 (c) shows that rutting is influenced by all the variables similarly. Figure 6 (d) shows that IRI is not much affected by the traffic variables.



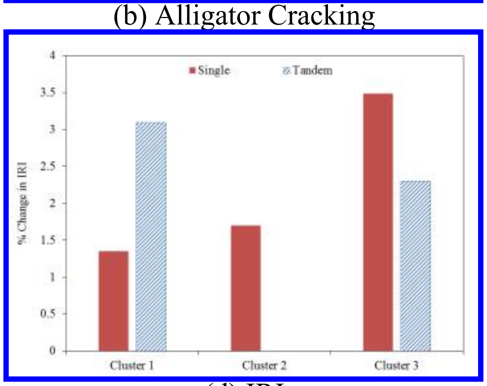
(a) Longitudinal Cracking



(b) Alligator Cracking



(c) Total Rutting



(d) IRI

Fig. 6. Effect of variability of traffic parameter on performance.

CONCLUSIONS

The traffic inputs required for the pavement design using the MPEDG were established by using the New Mexico LTPP data. Eight sections of NM from LTPP were selected and clustering was done to find out the similarities between the sites. After clustering the data a comparative study was conducted to establish the deviation of the distress prediction from the nationally-calibrated values for major traffic inputs. A sensitivity analysis was done to investigate the significance of these traffic inputs on the predicted distresses. It was found that longitudinal cracking is mostly sensitive to the tandem axle load distribution. Alligator cracking is sensitive to the single and tandem axle load distribution. Rutting is almost equally sensitive to axle loading, however IRI, is not sufficiently sensitive to the traffic variables to result in changes in the pavement design. Finally it can be said that using traffic data from NM instated of using default MEPDG value did have significant effect on pavement design and performance.

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Vehicle Rolling Resistance as Affected by Tire and Road Conditions

Wynand JvdM Steyn[1]; D. Lombard[2]; G. Mashabela[2]; J. Smith Rudolph[2]; and Webb Francois[2]

[1]Professor, Dept. of Civil Engineering, Univ. of Pretoria, Lynnwood Rd., Hatfield, 0002 South Africa. E-mail: wynand.steyn@up.ac.za
[2]Undergraduate Student, Dept. of Civil Engineering, Univ. of Pretoria, Lynnwood Rd., Hatfield, 0002 South Africa.

Abstract: When a tire rolls on a road surface, the road surface and tire interacts, resulting in the conversion of mechanical energy into heat. This has a major impact on the wear and tear of the tire and road surface as well as the vehicle fuel economy, with up to 20 per cent of the fuel used to overcome this rolling resistance between the road surface and the tire. The major parameters affecting the rolling resistance are the pavement surfacing characteristics, tire characteristics and operating conditions and vehicle characteristics and operating conditions. This paper evaluates the effect of tire inflation pressure, vehicle speed and pavement texture on the rolling resistance for typical passenger vehicles in South Africa.

INTRODUCTION

When a tire rolls on a road surface, there is interaction between the road surface and the tire, converting mechanical energy into heat. The force acting on the vehicle caused by the tire / pavement surface interaction is called rolling resistance. Minimizing the effect of rolling resistance improve the energy efficiency and fuel consumption of a vehicle, with a significant positive contribution towards a country's national fuel cost and carbon footprint. The main road surface property influencing rolling resistance is macro-texture. Various test methods can be used to determine the rolling resistance of a specific surface – the coast-down test was used in this paper. The objective of this paper is to demonstrate the relationships between rolling resistance and selected vehicle and pavement properties for typical passenger cars and standard pavement types in South Africa.

LITERATURE

Rolling resistance

Tire rolling resistance is the energy consumed per unit distance of travel as the tire rolls under a specific load (Hall, 2001). Rolling resistance is caused by the natural viscoelastic properties of rubber along with the tires internal components constantly bending, stretching and recovering between their loaded and unloaded phases and is equivalent to the energy required to maintain the movement of a rolling wheel (Venkatarman, 2007; Salaani et al, 2009). In order for the wheel to roll, the amount of energy aiding the movement of the vehicle should exceed the rolling resistance energy. The derivation of the rolling resistance equations can be found in Rutman (2007) (Equations 1 and 2). Typical rolling resistance coefficients for light passenger vehicles range around 0.012 and 0.015 (Terrassa, 2011).

$$F_{\mathrm{r}} = \mathrm{RRC} * m * g \quad (1)$$

$$RRC = \frac{V^2}{2*g*D} \quad (2)$$

where:
F_r = rolling resistance force [N]
RRC = rolling resistance coefficient
m = mass of body [kg]
g = acceleration of gravity [9.81 m/s^2]
v = velocity [m/s]
D = distance [m]

Vehicle component and road properties

Tire inflation pressure plays a major in the rolling resistance of a vehicle, with the correct inflation pressure optimizing the contact patch area and reducing the rolling resistance of a vehicle (Venkatarman, 2007). Under-inflation of tires by 31 kPa can cause an increase in rolling resistance of 6 per cent, while a 30 per cent increase can be expected in the rolling resistance when the tires are under-inflated by 100 kPa (LaClair, 2005). At lower speeds vehicles have a higher rolling resistance, but when the speed is increased the rolling resistance will decrease. As the vehicle speed is increased the air resistance of the vehicle is increased, becoming the dominant force in counteracting the forward motion of the travelling vehicle.

Road surfaces contribute to energy loss by intensifying tire deformation. Pavement stiffness impact the rolling resistance and fuel consumption of the vehicle, mainly due to the fact that a pavement has a dynamic deformation characteristic under a rolling tire. Stiffer, more rigid pavements reduce rolling resistance. Lu et al (2010) concluded that the stiffness of a pavement has a small yet significant impact on fuel consumption. Road surface texture affects the performance of a vehicle (Kummer, 1966). Texture is measured as the deviation of the surface from a true planar surface, with wavelengths less than 0.5 mm termed as “micro-texture” (Noyce et al., 2005). “Macro-texture” defines wavelengths within the range of 0.5 to 50 mm in surface geometry. The macro-texture of asphalt pavements is mainly controlled by the aggregate gradation and texturing methods. Surface geometries that have a wavelength of more than 50 mm, are termed “mega-texture”, and are often stated as large-scale roughness. Mega-texture tends to create vibration inputs in the tire and suspension system, and has the greatest influence on rolling resistance of a vehicle (Jackson et al., 2005). The measure for macro-texture is Mean Profile Depth (MPD) and it can be measured using the sand patch method or various laser-based and imaging based systems. The sand patch method is suitable for coarse bituminous surfaces and concrete pavements surfaces (Garbacz et al., 2013). Tires that are used on a rough macro- or micro-texture will deform more and suffer greater energy loss, and will experience faster tread wear. Micro-texture causes mechanical wear of tire when it rolls on a road surface, wearing the tire out, and reducing the tire tread depth (Ho, 2013).

Different types of pavement surfacings has unique surface properties. Texture of a concrete surface can be achieved by treating (brooming) the surface of the freshly placed concrete (Griffiths and Thom, 2007). Asphalt pavements are constructed using a mixture of aggregates, bitumen and fines. Surfacing seals are thin bitumen sprayed layers on a road surface, whereby a layer of aggregate is rolled onto the initial layer of bitumen. It is widely used in South Africa for construction of new roads with low to medium traffic. The cover aggregate increases the surface friction of the road surface, and the bituminous binder prevents the aggregates on the road surface from dislodging.

Rolling resistance measurement

Rolling resistance of a pavement surfacing can be measured using laboratory measurements on drums, trailers that are specially equipped for measurements on road surfaces and coast-down measurements. The most accurate method of measuring rolling resistance is in the laboratory by loading a tire on a drum (Karlsson et al., 2011). It is very useful when measuring the basic rolling resistance, and can be done with high accuracy. However, because of the drum's smooth surface, it is not possible to investigate the influence of macro-texture and unevenness of the surface and their influence on the rolling resistance (Hall and Moreland, 2001). Several specially equipped trailers are available internationally, where a wheel is attached to the trailer and the rolling resistance acting on the wheel is measured (Karlsson et al, 2011). The coast-down test is conducted by selecting a specific strip of road with a well-defined start and end point. The vehicle is allowed to roll freely between the two points. The vehicle will eventually slow down and come to a complete stop due to the different resistive forces acting on the vehicle, rolling resistance being one of them. The force acting on the vehicle is then derived by measuring the velocity for the free rolling vehicle. Coast-down rolling resistance is extensively used for calibration chassis dynamometers or for determining air resistance (Rune et al., 2011).

METHODOLOGY

Field data collection

Three different road surfaces were selected from specific areas around Pretoria, South Africa. These included an asphalt surface, a single seal bitumen surface and a rough jointed concrete pavement surface. During the field data collection, the following data were collected: