THE EFFECT OF HEAVY VEHICLE COMPOSITION ON DESIGN TRAFFIC LOADING CALCULATIONS (E80S)

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ABSTRACT

The composition of heavy vehicle traffic has changed dramatically on most of the major roads in southern Africa over the past 10 to 15 years. Observations in various countries confirmed that a continues shift is taken place in the composition of heavy vehicle traffic, which inter alia, leads to an increase in the growth in E80s per heavy vehicles (E80s/HV), the average calculated E80s/HV and subsequently the total calculated E80s. Available data has shown that there is a continues shift in composition from 2 and 3 axle's heavy vehicles to the larger 4 to 7 axle's heavy vehicle types. This can, inter alia, be explained by improved vehicle technology, economic growth as well as changes in legalisation (1996), which allows heavier loads to be carried, and better utilisation of heavy vehicles with an increase in economic activity. Cognizance is to be taken of these changes and the effect thereof needs to be incorporated into design traffic loading calculations. The objectives of this paper is to illustrate the changes that are taking place, to show how to incorporate these changes into design calculations and to present a technique, taking the changes in the heavy vehicle composition into consideration, that should be applied in the calculation of design traffic loading.

1. INTRODUCTION

Traffic loading in general can be defined as:

- the placement of traffic on a network, which includes both the use of space and the stressing of the pavement layers or structures (TRH16, 1991).
- the concept of the damage that is induced on the pavement structure in terms of an equivalent standard axle load of 80 kN. The damage caused by other axle load configurations relative to the standard axle can be defined as an equivalent standard axle (E80).

For the purpose of this paper, traffic loading will only be restricted as the contributing factor that influences the behaviour of pavement structures / damage to the pavement structure.

The calculation of the design traffic loading is an important aspect and input parameter in any pavement and pavement rehabilitation design. The primary aim of any rehabilitation design is to enable the rehabilitated pavement to carry, with adequate routine maintenance, the design traffic load without exhibiting excessive distress. In order to accurately predict and calculate the future design traffic loading on the roads, considerable effort is warranted to obtain accurate traffic and traffic loading data to facilitate it.

During the past 10 to 15 years there has been a continued shift in the traffic composition of heavy vehicles. These changes lead to an increase in the growth in E80s / Heavy Vehicles (HV), the average calculated E80s/HV, heavy vehicles (HV) and subsequently the total calculated E80s. Available data has shown that there is a continues shift in composition from 2 and 4 axle's heavy vehicles to the larger 5 to 7 axle's heavy vehicle types, which has been confirmed by results,

Proceedings of the 23rd Southern African Transport Conference (SATC 2004) 12 – 15 July 2004
ISBN Number: 1-920-01723-2 Pretoria, South Africa
Proceedings produced by: Document Transformation Technologies cc Conference Organised by: Conference Planners

analysed in this paper. This can, inter alia, be explained by improved vehicle technology, economic growth as well as changes in the permitted legal axle loads (legalisation (1996)), which allows heavier loads to be carried, and better utilisation of heavy vehicles with an increase in economic activity. The change in the composition of the heavy vehicles together with the changes in the permitted legal axle loads have lead to an increase in the design traffic loading. Therefore, cognizance is to be taken of these changes and the effect thereof needs to be incorporated into design traffic loading calculations.

2. SCOPE AND OBJECTIVES

The scope of this paper is limited to traffic loading data that has been obtained from 34 permanent counting stations widely spread around the nine provinces of South Africa (summarised in Table 1). The data has been obtained from the system of Comprehensive Traffic Observations (CTO) yearbooks from 1986 – 2002 carried out by Mikros Systems (Pty) Ltd (Mikros) on behalf of the South African National Roads Agency Ltd (SANRAL). The traffic data from the different counting stations does not necessarily represent the composition of traffic (traffic or axle load spectrum) for that particular province and was randomly selected to obtain enough results in order to make a meaningful assessment and for illustrative purposes.

Table 1. CTO traffic count stations (1986-2002) used for analysis purposes.

PROVINCE	TRAFFIC COUNT STATION NUMBER (TYPE)			
	TOLL PLAZAS		OTHER	HSWIM*
	S:M:L	CLASS	S:M:L	E80
WESTERN PROVINCE	191 N001/1 (PT)	2321 N001/1 (PT)	480 N001/8 (P)	3015 N001/1
		2323 N001/1 (PT)		
EASTERN PROVINCE	034 N002/8 (PT)	2310 N002/8 (PT)	104 R72/3 (P)	3013 N002/11
		2411		
FREE STATE		623 N001/13 (PP)	418 N001/15 (P)	
GAUTENG	241 N001/19 (PT)	2150 N001/19 (PT)	011 N001/21 (P)	
			048 N001/21 – (PP)	
LIMPOPO	301 N001/24 (PT)	2140 N001/24 (PT)	041 N001/23 – (P)	3007 N001/20
MPUMALANGA	413 N004/4 (P)	2370 N004/4 (PT)		
KWAZULU NATAL	246 N003/4 (PT)	2240 N003/4 (PT)	003 N003/6 (P)	3544 N001/26
	377 N003/1 (PT)	2270 N003/1 (PT)		3052 N004/3
NORTERN CAPE			108 N012-TR013/6 (P)	3003 N003/3
NORTH WEST		2500 N004-P002/2 (PT)	519 N004/12 (P)	3062 R566-K8

* HSWIM – High Speed Weigh in Motion E80 measurements as obtained from Mikros (CTO stations)
(Station type) = (P) – Permanent; (PT) – Permanent Toll, (PP) – Permanent Piezo

The objectives of this paper are to:

- illustrate the changes that are taking place in the composition of heavy vehicles,
- show how to incorporate these changes into design calculations, and
- present a technique, taking the changes in the heavy vehicle composition into consideration, that under certain circumstances can be usefully applied in the calculation of design traffic loading.

The calculation of the design traffic loading for a section of road depends on various factors, inter alia, the type of data available (e.g. vehicle classification, method of traffic counting, obtaining of axle load (weighing), calculation of growth rates etc) and the application thereof. Thus engineering judgement needs to be applied in order to assess the available data and to use the available data optimally.

3. IMPORTANT CHANGES THAT NEED TO BE CONSIDERED

3.1 General

Traffic loading could be considered to consist of the following three elements (TRH16, 1991):

- Vehicle loading, i.e. the force and consequently the damage applied to the pavement by a legally - loaded vehicle,
- Vehicle overloading, i.e. the force and consequently the damage applied by an overloaded vehicle,
- Vehicle lading, i.e. the extent to which the vehicles' load capacity is utilised.

The above three elements together with the growth in heavy vehicles play an important role in the calculation of the design traffic loading and the prediction of the damage induced by the heavy vehicle composition on a section of road. These three elements are interwoven into the heavy vehicle composition and subsequent in the average E80/HV factors that are used for design calculation purposes. The influence and impact of the changes experienced in some of the above three elements will be briefly discussed and outlined.

3.2 Shift in Heavy Vehicle Composition (% HV Split)

The composition of heavy vehicle traffic has changed dramatically on most of the major roads in southern Africa over the past 10 to 15 years. Observations in various countries confirmed that a continued shift is taking place in the composition of heavy vehicle traffic, which inter alia, leads to an increase in the growth in E80s per heavy vehicles (E80 / HV), the average calculated E80 / HV and subsequently the total calculated E80s. The composition of the heavy vehicle traffic can generally be split into 2-axles, 3 axles, 4-axles, 5 axles, 6-axles etc. These different axle load configurations (heavy vehicles) are then grouped / classified into the following three classes: short, medium and long. In general short vehicles are defined as heavy vehicles with 2 axles, medium to heavy vehicles with 3 and 4 axles and long to heavy vehicles with 5 or more axles.

To illustrate this continued shift in the composition of heavy vehicles, 6 permanent traffic counting stations were randomly selected from the 34 traffic counting stations to show these "trends". In Figure1 the composition of heavy vehicles (short, medium, long) as a % split of the heavy vehicles are shown. All the figures, illustrated in Figure 1, show an increase in the % long compared to the % short and % medium. Almost all of the traffic counting station's data also showed a decrease (decline) in the % short and in some instances a decrease in the % medium.

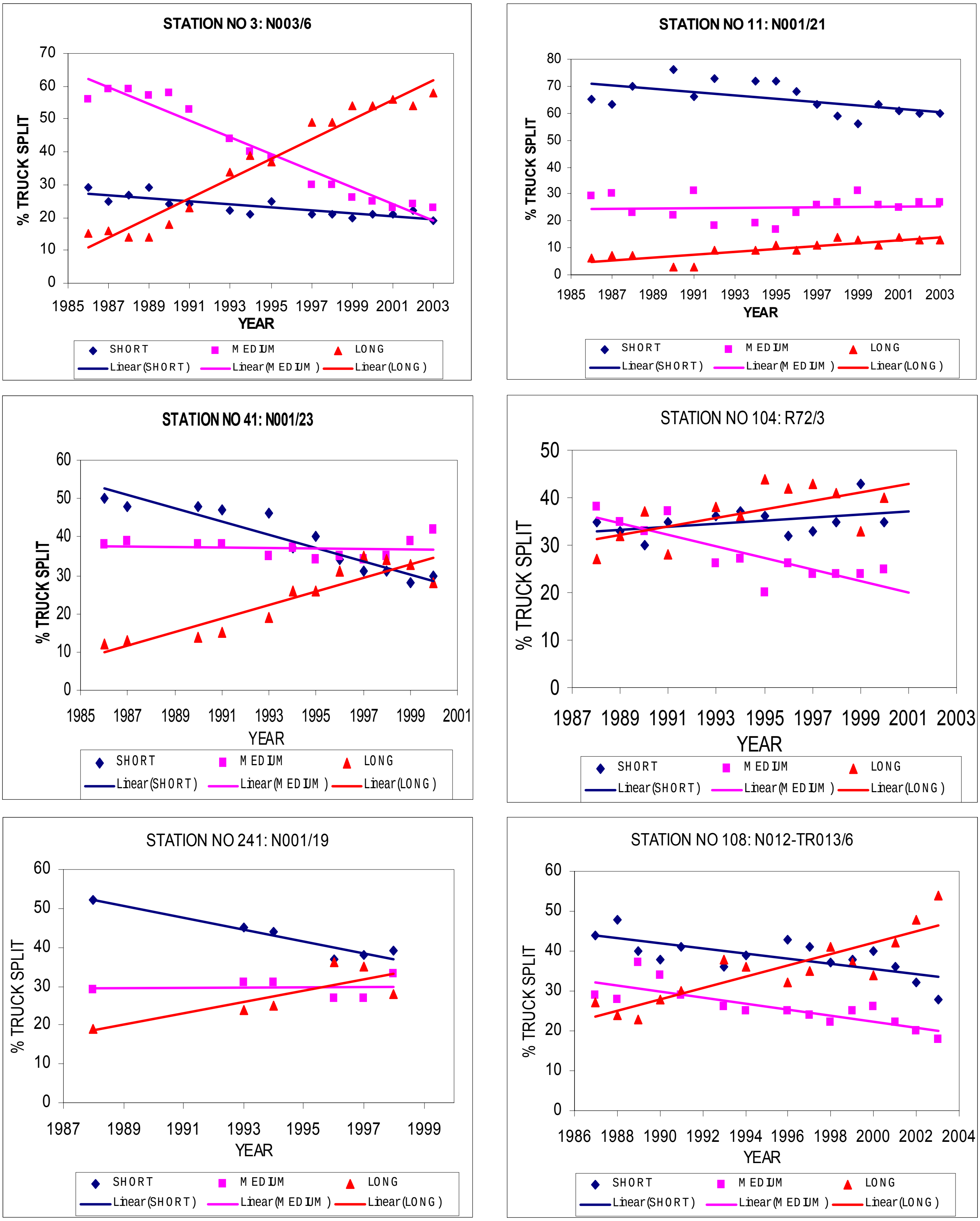


Figure 1. Shift in heavy vehicle composition (% truck split) ("trends") as obtained from different CTO traffic counting stations.

3.3 Increase in the Average E80 / HV Factors

Since the growth in E80s depend on the growth in heavy vehicles as well as a growth in E80 / HV, the shift in the composition of the heavy vehicles (with associated growth in heavy vehicles) lead to a definite increase in the growth in E80 per heavy vehicles as well as the average E80 / HV. In order to incorporate these changes, this important aspect needs to be grasped and understood to make a meaningful assessment of E80 growth.

In TRH 16 (1991), reliable estimates for average E80s for different heavy vehicles configurations are given. However, these configurations dated back to 1991 and needs to be reviewed and updated. A recent study compiled for the Southern African Transport and Communications Commission (SATCC, 1998) showed that there has been a marked increase in the average E80 for the different heavy vehicles configurations. These E80 / HV factors are summarised in Table 2.

Table 2. Average E80 factors for the different heavy vehicle configurations.

HEAVY VEAHICLE TYPE	TRH 16 (1991)			SATCC (1998)			CTO STATIONS (1986-2002) - HSWIM #		
	Min	Max	Ave.	Min	Max	Ave.	Min	Max	Ave.
2 Axles – Buses	0.41	1.52	**0.73**	0.40	1.80	**1.20**	0.60	2.90	**1.80**
2 Axles	0.30	1.10	**0.70**	0.30	2.00	**1.50**	0.30	1.70	**0.90**
3 Axles	0.80	2.60	**1.70**	0.50	3.00	**2.00**	1.00	3.20	**2.10**
4 Axles	0.80	3.00	**1.80**	0.70	3.50	**2.50**	1.00	3.00	**2.10**
5 Axles	1.00	3.00	**2.20**	1.00	4.50	**3.20**	1.20	5.00	**3.50**
6 Axles	1.60	5.20	**3.50**	1.20	6.00	**4.70**	2.50	4.40	**3.70**
7+ >Axles	3.80	5.00	**4.40**	2.00	8.00	**6.00**	3.00	7.50	**5.30**

- HSWIM - High Speed Weigh in Motion measurements as obtained from Mikros (CTO stations)

Also given in Table 2 are the average E80 factors for different heavy vehicle configurations measured during this study. As can be seen from the data presented in Table 2 there are a definite increase in the average E80 factors for the different heavy vehicle types. Thus taking this into consideration, it can be concluded that this increase in the average E80s for the different heavy vehicle types will have an impact in the calculation of the total E80s. It is recommended that the TRH 16 (1991) be reviewed and updated with new findings and research that have been recently undertaken.

During this study, average E80 factors for the different heavy vehicle classes (short, medium and long) have also been calculated at different selected traffic counting stations, as shown in Table 3. These average E80 values need to be used carefully during the design and need to be calculated, if enough information is available, for every traffic study separately. An interesting observation is that the average E80 for some of the sites are in excess of 3.0 with an average E80 calculated for all the sections during this study of 2.5.

To illustrate how to meaningfully incorporate the changes that has taken place (e.g. the shift in heavy vehicle split, the growth in E80 etc), a practical example using CTO Traffic Counting Station No 3 on the N003/6 is given in “Design Traffic Loading Calculations”.

Table 3. Measured average E80 / HV split (class) from HSWIM[#] studies and from other sources.

LOCATION - PROVINCE / SITE IDENTIFIER	YEAR	AVERAGE E80s / HV			
			HEAVY VEHICLE SPLIT - CLASS		
			2 AXLES - SHORT	3+4 AXLES - MEDIUM	5^+ > AXLES - LONG
WESTERN PROVINCE / 3015 #	2000	0.70	0.09	0.33	1.42
LTPS [##] (1996) CPT - JHB	1996	1.82	0.44	0.86	2.56
EASTERN PROVINCE / 3013 #	2000	6.68	1.82	8.51	9.37
GAUTENG / 3007 #	2000	1.27	0.37	1.59	3.11
LIMPOPO / 3544 #	2001	3.02	0.98	1.24	5.11
LTPS [##] (1996) JHB - BB	1996	1.58	0.84	1.59	4.78
MPUMALANGA / 3052 #	2002	2.39	0.47	1.44	3.79
KWAZULU NATAL / 3003 #	1999	3.01	0.80	2.01	4.77
LTPS [##] (1996) DUR - JHB	1996	2.31	0.61	1.22	3.44
NORTH WEST / 3062 #	2002	2.81	0.37	1.35	5.45
BOTSWANA (NATIONAL AVERAGE)	1995		0.46	1.89	3.36
AVERAGE - ALL SITES #	2000/2	2.50	0.60	1.50	4.30

[#] - HSWIM - High Speed Weigh in Motion measurements as obtained from Mikros (CTO stations)
[##] - LTPS (1996) - Land and Transport Pricy Survey (Representative E80); CPT - Cape Town; JHB - Johannesburg; BB - Beit Bridge; DUR - Durban

3.4 Changes in Legal Axle Load Limits and Overloading

In 1996, the permissible legal axle loading for heavy vehicles (different axle types) was changed as shown in Table 4 (e.g. the permissible load for a single axle has been changed from 8,200 t to 9,000t). From these results it is clear that the heavy vehicles have now been permitted to legally increase the number of E80s/axle between 45.1% and 70.6%.

Table 4. Influences of changes in legal axle loads.

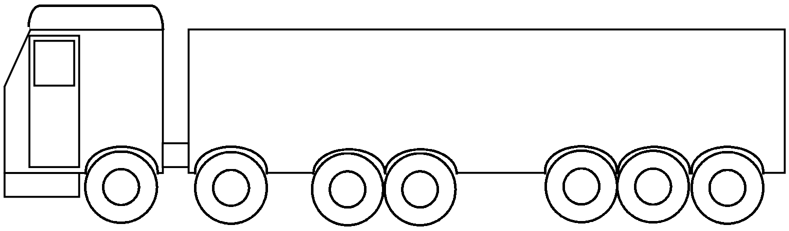
	1995:		1996:		
Axle type	**Permissible Load**	**Equivalent E80's**	**Permissible Load**	**Equivalent E80's**	**% Additional Legal E80's**
Single Axles (4 Tyres)	8,200	1.00	9,000	1.45	45.1
Tandem Axle Units	16,400	2.00	18,000	2.90	45.1
Tridem Axle Units	21,000	1.59	24,000	2.72	70.6

To further illustrate the impact of an increase in the legal axle load limit, a heavy vehicle truck simulating a 6 axle load configuration is used for demonstrative purposes. In Table 5 the expected axle load and E80 factors for the same truck (using the different legal axle loads) were calculated to show the impact that the new increased legalization has on the average E80 / HV type (assumption made is that the truck is fully loaded).

From these results the following conclusions can be made:

- the newly permitted average E80 / HV type is almost double the average permitted E80 / HV type measured before the new legalislation has been introduced.
- The changes in permissible legal axle loads on the E80 factors will have a pronounce impact on the traffic loading calculations of roads.

Table 5. E80 / HV calculations due to changes in legal axle loads in 1996.



Legal Load - Old	Front T/T	Rear T/T	Rear T/r	Total
Illustrative / Expected load (fully loaded)				
Maximum Legal Load (Kg)	5,200.00	16,400.00	21,000.00	
P - Axle Load (KN)	50.96	160.72	205.80	
n - Relative Damage Exponent	4.0	4.0	4.0	
F - Load Equivalency Factor (E80)	**0.16**	**2.04**	**1.62**	**3.82**
Legal Load - New	**Front T/T**	**Rear T/T**	**Rear T/r**	**Total**
Illustrative / Expected load (fully loaded)				
Maximum Legal Load (Kg)	6,000.00	18,000.00	24,000.00	
P - Axle Load (KN)	58.80	176.40	235.20	
n - Relative Damage Exponent	4.0	4.0	4.0	
F - Load Equivalency Factor (E80)	**0.29**	**3.02**	**2.77**	**6.01**

4. DESIGN TRAFFIC LOADING CALCULATIONS

4.1 General

In order to determine the design traffic loading of a particular section of road, in general, the following steps need to be followed:

- Traffic and traffic loading data - gathering of all information available,
- Axle load data – assesses and determine the E80 factors that will be used during the design calculation process,
- Growth rates - determine the past and future estimated growth rates (e.g. Average Annual Daily Traffic (AADT), Annual Average Daily Truck Traffic (AADTT) or heavy vehicle growth (HV) and E80),
- Sensitivity analyses – determine criteria and set up different scenarios for a sensitivity analysis.
- Calculation of the total E80 derived from the different scenarios predicted in the sensitivity analysis.

4.2 Traffic and Traffic Loading Data

The historical traffic count data was obtained from Mikros Systems (Pty) Ltd (Mikros) traffic count data (CTO stations 1986-2002). This data was used to determine past traffic growth rates and to predict future expected traffic growth rates as discussed in this report under “Growth Rates”.

The following information was obtained:

- Annual Average Daily Traffic (AADT) volumes for the different vehicle classes
- Average Daily Truck Traffic (ADTT) - Spilt in trucks (%)
- % Heavy Vehicles
- Composition of the heavy vehicles (i.e. 2 axles (short), 3 + 4 axles (medium), >5 axles (long))
- Directional split in traffic (distribution / composition of traffic flows)
- Measured E80 / HV for different heavy vehicle configurations

Table 6. Traffic data as obtained from traffic counting station (CTO station No 3 – N003/6) and projected traffic growth.

YEAR	ANNUAL AVERAGE DAILY TRAFFIC (AADT)	HEAVY VEHICLES (HV) (AADTT)	% HEAVY VEHICLES (%HV)	HEAVY VEHICLE SPLIT (%)			E80 / DAY	PROJECTED TRAFFIC GROWTH FOR TRAFFIC COMPOSITION WITH THE CALCULATED GROWTH RATES (%)					
				SHORT	MEDIUM	LONG		AADT		AADTT		E80 /DAY	
				E80 / HV									
				0.6	2.5	4.1		LN	EXP	LN	EXP	LN	EXP
1986	4,477	816	18.23	29	56	15	1786	5527	4960	921	1065	1740	2169
1987	5,149	948	18.41	25	59	16	2162	5787	5145	1025	1134	2117	2360
1988	5,585	1218	21.81	27	59	14	2693	6047	5338	1130	1207	2493	2567
1989	6,595	1340	20.32	29	57	14	2912	6306	5537	1235	1285	2870	2792
1990	7,168	1344	18.75	24	58	18	3134	6566	5744	1340	1368	3247	3037
1991	7,694	1502	19.52	24	53	23	3623	6826	5959	1445	1456	3623	3303
1992								7086	6182	1550	1550	4000	3593
1993	7,496	1608	21.45	22	44	34	4223	7346	6413	1655	1650	4377	3908
1994	7,591	1739	22.90	21	40	39	4739	7605	6652	1759	1756	4753	4251
1995	8,472	1936	22.90	25	38	37	5067	7865	6901	1864	1869	5130	4624
1996	8,590	2061	24.00					8125	7159	1969	1990	5507	5030
1997	8,830	2129	24.10	21	30	49	6142	8385	7427	2074	2118	5883	5471
1998	9,087	2003	22.00	21	30	49	5779	8644	7704	2179	2255	6260	5951
1999	9,234	2349	25.40	20	26	54	7009	8904	7992	2284	2400	6637	6474
2000	8,828	2204	25.00	21	25	54	6535	9164	8291	2389	2555	7013	7042
2001	8,938	2341	26.20	21	23	56	7016	9424	8601	2493	2720	7390	7659
2002	9,233	2644	28.60	22	24	54	7789	9684	8922	2598	2895	7767	8331
2003	9,248	2878	31.10	19	23	58	8827	9943	9256	2703	3082	8143	9062

Calculation of the different growth rates (%) for different time periods

% GROWTH ('86-'03)	**4.4%**	**7.7%**	**3.2%**	**-2.5%**	**-5.1%**	**8.3%**	**9.9%**	**3.5%**	**3.7%**	**6.5%**	**6.4%**	**9.5%**	**8.8%**
% GROWTH ('97-'03)	**0.8%**	**5.2%**	**4.3%**	**-1.7%**	**-4.3%**	**2.9%**	**6.2%**	**2.9%**	**3.7%**	**4.5%**	**6.4%**	**5.6%**	**8.8%**
% GROWTH ('00-'03)	**1.6%**	**9.3%**	**7.5%**	**-3.3%**	**-2.7%**	**2.4%**	**10.5%**	**2.8%**	**3.7%**	**4.2%**	**6.4%**	**5.1%**	**8.8%**

This historical traffic data together with the recently measured average E80s /HV configurations (HSWIM data) were used as input to determine the future traffic loading on the road. A summary of the traffic data as obtained from the traffic count station is given in Table 6. A 20 year design period is used for analysis purposes.

4.3 Axle Load Data

4.3.1 General

The expected traffic load to be carried by the pavement structure is calculated as the number of equivalent standard 80 kN dual wheel single axle loads (E80's or ESA's). Table 4 gives typical values of E80's per vehicle type measured in southern Africa (TRH16 (1991) and SATCC (1998)).

These values could vary considerably from route to route. Ideally, E80 factors should be obtained for each route to increase the accuracy of traffic loading analyses. However, E80 factors were measured on the route and can be used meaningfully.

4.3.2 Measurement of Average Design E80 / HV

The average E80s/HV factors (as obtained from the HSWIM data) for the different heavy vehicle configurations (for this particular road) together with the composition of the heavy vehicles were used to calculate the average E80 / HV factors for the heavy vehicle split (short, medium and long) and subsequently the average design E80 / HV for the road. The design input parameters are given in Table 7.

Table 7. Input parameters into the design traffic loading calculations.

2003 DATA		HV COMP. (% of HV)	HV SPLIT (%)	E80's / HV CLASS	E80's / DAY	VEHCILE CLASS / DAY	AVE. E80 / HV
AADT	9,248	Class 1 :	68.90	0	0	6,372	
% Heavy Vehicles	31	Class 2 :	6.44	0.80	476	595	**3.295**
Light Vehicles	6,372	Class 3 :	7.37	2.01	1,370	682	
Heavy vehicles	2,876	Class 4 :	17.29	4.77	7,628	1,599	
Design Distr. factor	95%						
Dir. Split (%)	50:50	Total	100		9,474	9,248	

4.4 Growth Rates

4.4.1 General

Observations over the last 20 years in various countries have shown that a growth rate in E80's per heavy vehicle occurs on most roads. This can, inter alia, be explained by improved vehicle technology, which allows heavier loads to be carried, and better utilisation of heavy vehicles with an increase in economic activity.

Since the variations in traffic loading are complex, an important aspect in the prediction of traffic growth is to get enough information to show the long term growth or decline ("trend"). The growth in E80 (an exponential compound growth rate) needs to be done over a period of at least 5 years (preferable) and should consist of mathematically fitting the "best line" (TRH16, 1991). Growth rates obtained from short term surveys (2-3 years) may not necessarily reflect a long term trend and should be used with caution. For the purpose of this study both linear as well as an exponential compound growth rates were calculated – for comparison reasons. The growth rates for the different vehicle types etc. are summarised in Table 6. Three different growth rates were determined from the data in order to assess the growth that has taken place in both the short term ('00-'03), the medium term ('97-'03) and the long term ('86-'03). This was taken into consideration during the determination of the different scenarios to be used in the sensitivity analysis.

4.4.2 Growth in E80s

a) Historical growth rates

The past / historical traffic growth rates were calculated from the data received from Mikros and are given in Table 6.

From the historic traffic data (1986 to 2003), a growth rate of 3.7 per cent per annum was calculated for the annual average daily traffic (AADT). A 6.4 per cent per annum growth rate for the annual average daily truck traffic (AADTT) with a growth rate in total E80's of 9.5 per cent. The growth in E80s / HV is mainly due to a shift in heavy vehicle split as well as a general increase in heavy vehicles over the past 10 to 15 years. It needs to be emphasised that there is a major difference between the growth rate in AADT and the growth rate in E80s. Design engineers often make the mistake to use the growth in AADT or HV instead of a growth in E80 to calculate the total E80s, which subsequently lead to erroneous design traffic loading estimates (usually an underestimation of design traffic loading).

From the data available it can be seen that the percentage long vehicles (heavy) have increased from 15 per cent (1986) to 58 per cent (2003) while the short and medium trucks decreased from 56 per cent (1986) to 23 per cent (2003) and from 29 per cent (1986) to 19 per cent (2003) respectively. The different growth rates are shown in Figure 2.

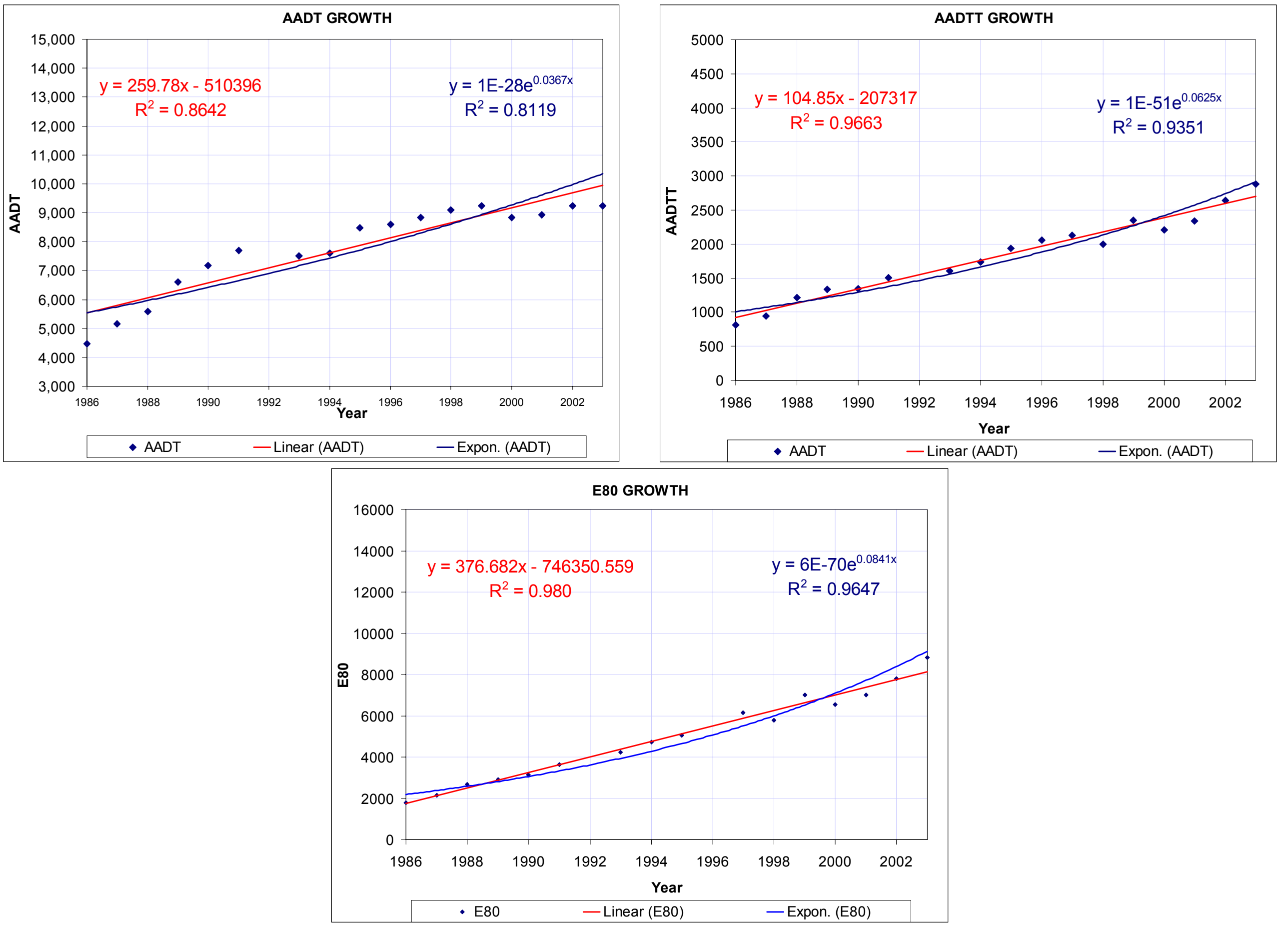


Figure 2. Growth rate "trends" measured for the annual average daily traffic (AADT), annual average daily truck traffic (AADTT) and the E80s for CTO traffic count station No 3.

b) Future growth rates

Future traffic loading should be based on past trends taking into account all additional information such as expected new developments (new toll roads etc). Many unknown factors could influence these predictions and hence, a sensitivity analysis should be done to investigate low, medium (probable) and high scenarios.

4.5 Sensitivity Analysis Strategy

The expected E80 growth rate on a specific road can be determined for a different range of scenarios and can be best assessed through a sensitivity analysis. For the purpose of this traffic loading analysis a sensitivity analysis has been done using the heavy vehicle growth and E80 growth rates from the data available. Traditionally the E80 growth rate is calculated using the following formula (1):

$$\text{E80 growth rate} = [(1+h/100) \times (1+v/100)-1] \times 100 \quad (1)$$

where:

h = heavy vehicles growth rate
v = E80s per heavy vehicle growth rate

Thus, the growth in E80's depends on factors such as:

- Growth in total traffic.
- Growth in the percentage heavy vehicles as a percentage of total traffic.
- Growth in E80s per heavy vehicle.

The first two factors can be combined as the growth in heavy vehicles. Since the growth rate in E80s has already been determined (with the data available), which inter alia, already taken into account the growth in heavy vehicles as well as the changes that have been taken place in the heavy vehicle composition (HV split), it is now possible to determine and assess what the growth in E80/HV was for this particular section of road. Assuming that the calculated growth in heavy vehicles and E80s from the historic data is the most probable (medium) scenario for future growth, a sensitivity analysis for the different scenarios can now be modelled for calculation purposes.

A sensitivity analysis was done for the N003/6 road using different E80 growth rates.

For the purpose of this study the following E80 growth rates scenarios were considered to be reasonable for this section of road:

- Low estimate: 4.5% growth in E80s
- Probable (Prob.)/ Medium estimate: 6.5% growth in E80s
- High estimate: 8.5% growth in E80s

Using the different growth rates (heavy vehicles and E80s) as obtained from Table 6 and Figure 2 as input, it is now possible to determine the E80 / HV growth for this specific section of road (as illustrated in Table 8). For example, with the long term growth in heavy vehicles at 6.4% - 6.5% (probable scenario) and with the long term growth in E80 of 9.1% (between 8.8% and 9.9%)(probable scenario), it is now possible to determine the growth in E80/HV (2.4%) for different scenarios.

Table 8. Sensitivity analysis for different scenarios in order to determine E80 growth rates.

			GROWTH IN HEAVY VEHICLES (%)		
			LOW	PROBABLE (MEDIUM)	HIGH
			4.5%	**6.5%**	8.5%
GROWTH IN E80 / HEAVY VEHICLES (%)	LOW	1.0%	5.5%	7.6%	9.6%
	PROBABLE (MEDIUM)	**2.4%**	7.0%	**9.1%**	11.1%
	HIGH	3.2%	7.8%	9.9%	12.0%

4.6 Design Traffic Loading Calculations

4.6.1 Past Traffic Loading

The past cumulative traffic loading for each of the respective traffic scenarios were calculated using the following formula (2).

$$N_P = E_0\left(\frac{(1+i)^{n+1}-1}{i(1+i)^n}\right) \qquad \text{(After TRH12, 1997)} \qquad (2)$$

where:

E_0 = annual equivalent 80 kN axle loads in the year of investigation (E80's) (assume the road will be opened the following year)

i = mean E80 growth rate during the past existence of the pavement (per cent / 100)

n = age of the pavement (years)

Table 9. Calculation of total E80s for different scenarios using data from the sensitivity analysis.

ANALYSIS / PERIOD		**E80 GROWTH RATE (%)**			**E80 / YEAR (BOTH DIRECTIONS)**			**TOTAL E80s -LOW**	**TOTAL E80s PROBABLE**	**TOTAL E80s - HIGH**
YEAR (YR)	**YR NO**	**LOW**	**PROB**	**HIGH**	**LOW**	**PROB.**	**HIGH**	**CUM. SUM**	**CUM. SUM**	**CUM. SUM**
2003	0	7.0%	9.1%	12%	3.46.E+06	3.46.E+06	3.46.E+06	1.64.E+06	1.64.E+06	1.64.E+06
2004	1	7.0%	9.1%	12%	3.70.E+06	3.77.E+06	3.87.E+06	3.40.E+06	3.43.E+06	3.48.E+06
2005	2	7.0%	9.1%	12%	3.96.E+06	4.11.E+06	4.34.E+06	5.28.E+06	5.39.E+06	5.54.E+06
2006	3	7.0%	9.1%	12%	4.24.E+06	4.49.E+06	4.86.E+06	7.30.E+06	7.52.E+06	7.85.E+06
2007	4	7.0%	9.1%	12%	4.54.E+06	4.89.E+06	5.44.E+06	9.45.E+06	9.84.E+06	1.04.E+07
2008	5	7.0%	9.1%	12%	4.85.E+06	5.34.E+06	6.09.E+06	1.18.E+07	1.24.E+07	1.33.E+07
2009	6	7.0%	9.1%	12%	5.19.E+06	5.82.E+06	6.82.E+06	1.42.E+07	1.51.E+07	1.66.E+07
2010	7	7.0%	9.1%	12%	5.56.E+06	6.35.E+06	7.63.E+06	1.69.E+07	1.82.E+07	2.02.E+07
2011	8	7.0%	9.1%	12%	5.95.E+06	6.92.E+06	8.55.E+06	1.97.E+07	2.14.E+07	2.42.E+07
2012	9	7.0%	9.1%	12%	6.36.E+06	7.55.E+06	9.57.E+06	2.27.E+07	2.50.E+07	2.88.E+07
2013	10	7.0%	9.1%	12%	6.81.E+06	8.23.E+06	1.07.E+07	2.59.E+07	2.89.E+07	3.39.E+07
2014	11	5.5%	7.6%	9.6%	7.19.E+06	8.85.E+06	1.17.E+07	2.94.E+07	3.31.E+07	3.95.E+07
2015	12	5.5%	7.6%	9.6%	7.59.E+06	9.52.E+06	1.29.E+07	3.30.E+07	3.77.E+07	4.56.E+07
2016	13	5.5%	7.6%	9.6%	8.01.E+06	1.02.E+07	1.41.E+07	3.68.E+07	4.25.E+07	5.23.E+07
2017	14	5.5%	7.6%	9.6%	8.45.E+06	1.10.E+07	1.55.E+07	4.08.E+07	4.78.E+07	5.96.E+07
2018	15	5.5%	7.6%	9.6%	8.92.E+06	1.19.E+07	1.69.E+07	4.50.E+07	5.34.E+07	6.77.E+07
2019	16	5.5%	7.6%	9.6%	9.41.E+06	1.27.E+07	1.86.E+07	4.95.E+07	5.95.E+07	7.65.E+07
2020	17	5.5%	7.6%	9.6%	9.94.E+06	1.37.E+07	2.03.E+07	5.42.E+07	6.60.E+07	8.61.E+07
2021	18	5.5%	7.6%	9.6%	1.05.E+07	1.48.E+07	2.23.E+07	5.92.E+07	7.30.E+07	9.67.E+07
2022	19	5.5%	7.6%	9.6%	1.11.E+07	1.59.E+07	2.44.E+07	6.44.E+07	8.05.E+07	1.08.E+08
2023	20	5.5%	7.6%	9.6%	1.17.E+07	1.71.E+07	2.68.E+07	7.00.E+07	8.86.E+07	1.21.E+08

4.6.2 Future Design Traffic Loading

The design traffic loading for the N003/6 road is based on a sensitivity analysis using the scenarios and growth rates as discussed in "Sensitivity Analysis Strategy". The cumulative sum of E80s (future design traffic loading) for a low, medium (probable) and high scenario for a 20 year design period is given in Table 9. Results from Table 9 show that the 20 year design traffic can range from 70 x 10^6 E80s (low), 87 x 10^6 E80s (probable) to 121 x 10^6 E80s (high).

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions can be made:

- The composition of heavy vehicle traffic has changed dramatically on most of the major roads in southern Africa over the past 10 to 15 years. These changes have been confirmed through various traffic counting station data. There has been a continues shift towards the "long" heavy vehicle composition, which leads to an increase in the growth in E80s, the average E80s / HV and subsequently the total E80s calculated for a specific road.
- Due to an increase in the permitted legal axle loads, a general growth in heavy vehicles together with a continues shift in the composition of heavy vehicles, there are a definite increase in the average E80 / HV.
- The changes in the heavy vehicle composition etc must be incorporated into design traffic loading calculations. A technique on how to incorporate and apply these changes in the calculation of the design traffic loading has been presented.
- The effect of an increase in the permitted legal axle loads has a major impact on the permitted legal E80 /HV. Heavy vehicles are now permitted to legally carry between 45.1% (single axle and tandem axle units) and 70.6% (tridem axle units) more E80s per respective axles. This has a pronounce impact on the traffic loading on the roads.

5.2 Recommendations

The following recommendations can be made:

- It is recommended that the TRH 16 (1991) be reviewed and updated with new findings and research that have been recently undertaken.
- It is recommended that more information is gathered, analyzed and processed to successfully provide new factors / norms to accommodate the shift towards the "long" heavy vehicle composition on the roads in southern Africa.

6. ACKNOWLEDGEMENTS

The information provided by the following persons / organisations in compiling this paper is appreciated and gratefully acknowledge:

Mr. Geoff Ackerman, South African National Roads Agency Ltd (SANRAL)

Me. Michelle van der Walt, Mikros

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THE EFFECT OF HEAVY VEHICLE COMPOSITION ON DESIGN TRAFFIC LOADING CALCULATIONS (E80S)

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