Cost Estimation of Road Wear Due To Heavy Vehicles on the Namibian Paved Network

L Kemp
Built Environment, CSIR, PO Box 395, Pretoria, 0001; Email: lkemp@csir.co.za

PA Nordengen
Built Environment, CSIR, PO Box 395, Pretoria, 0001; Email: pnordengen@csir.co.za

AJ Steenkamp
Built Environment, CSIR, PO Box 395, Pretoria, 0001; Email: asteenkamp@csir.co.za

T Ithana
Namibia Roads Authority; Email: IthanaT@ra.org.na

***Abstract*—This paper presents the results of a newly-developed methodology that quantifies the road wear caused by heavy vehicles on the Namibian paved road network in terms of equivalent standard axles and a monetary value. This was achieved by converting the spectrum of heavy vehicles travelling on the Namibian trunk road network per road section in one year to an equivalent number of standard axle-km travelled in the same year and multiplying the standard axle-km by the estimated unit construction and maintenance costs per uniform pavement section on the road network. The conversion of the spectrum of heavy vehicles to an equivalent number of standard axle-km travelled involved the calculation of load equivalency factors for the different vehicle configurations using the South African Mechanistic Empirical Design Method, which is based on data obtained from the Heavy Vehicle Simulator (HVS) and Stress-In-Motion (SIM) systems over the past few decades. Data obtained from the Namibia Roads Authority included traffic count data, weighbridge data, road network data and pavement data. This study has allowed for the development of a suitable platform to efficiently, and with improved accuracy, calculate the cost of road wear caused by heavy vehicles on the Namibian paved road network. The developed methodology will enable the Roads Authority to monitor changes in the road wear costs attributed to heavy vehicles. It also provides the Road Authority with a tool to determine the effect of initiatives such as improved overload control and for making more informed strategic decisions.**

***Keywords*—road wear; heavy vehicles; Namibia; cost estimation**

I. INTRODUCTION

During 2017 the CSIR developed and registered a methodology as a technology demonstrator tool for determining reasonably accurate cost estimations of road wear caused by heavy vehicles on a paved road network [1]. This was part of a project for the Namibia Roads Authority (NRA).

This study allowed for the development of a suitable platform to efficiently and accurately calculate the cost of road wear caused by heavy vehicles on the Namibian paved road network. Future studies based on more recent data will enable the NRA to monitor changes in the road wear costs attributed to heavy vehicles. It also provides the Roads Authority with a tool to determine the effect of initiatives such as improved overload control and to make informed strategic decisions.

II. BACKGROUND

The Namibian road network covers a total distance of just less than 46 500 km (Road Referencing System: Network 10), comprising trunk, main and district roads as presented in Fig. 1 and Table I. Approximately 7 570 km of the total road network is paved. The trunk network consists of 4 778 paved kilometres, which is 63% of the total paved network.

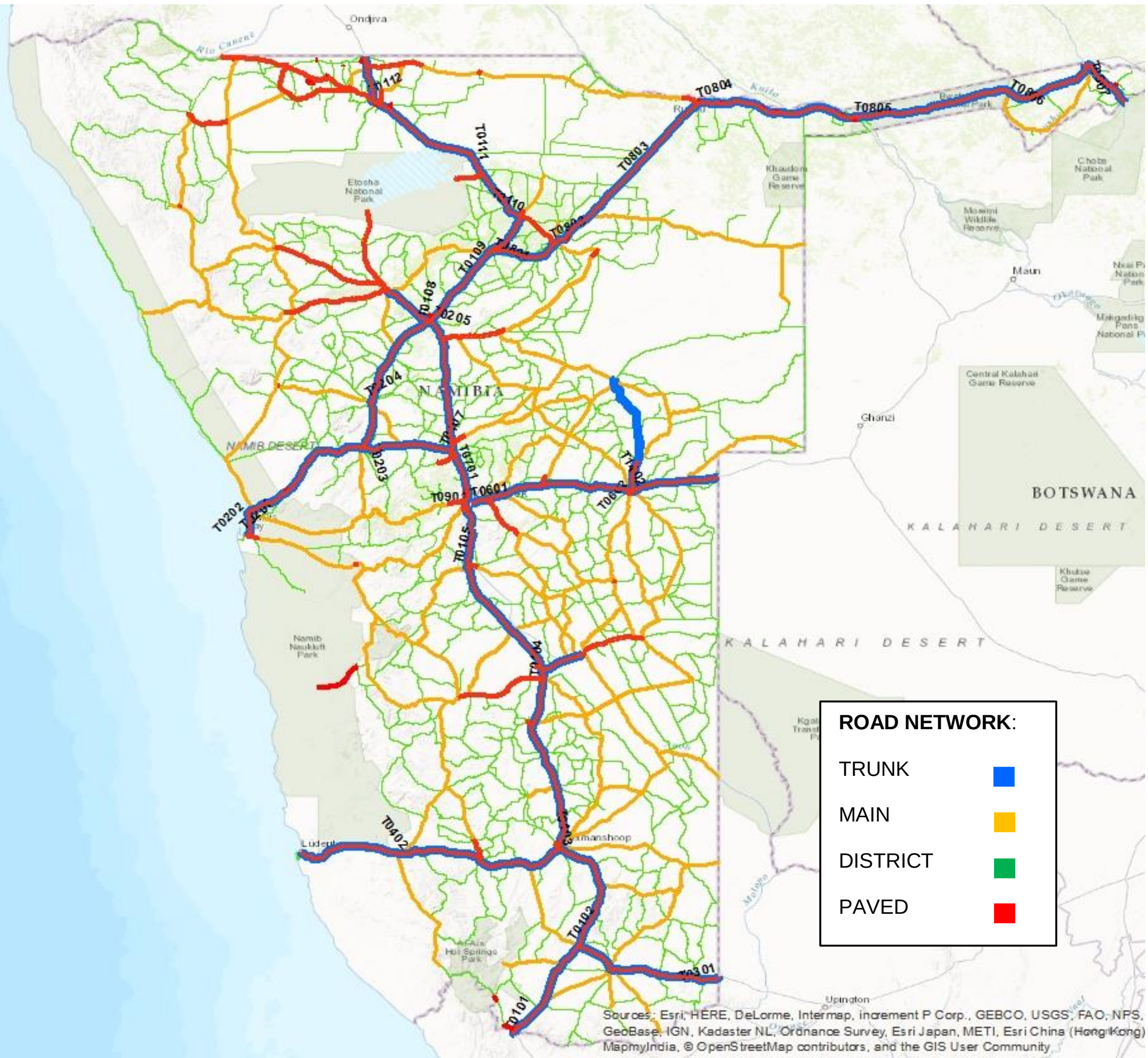

Fig. 1.Visual summary of the Namibian road network

As part of Namibia's development plan to control overloading of heavy vehicles on the road network, weighbridge facilities were constructed at strategic locations on the primary routes. Data from nine of these weighbridge facilities were utilised for this analysis. A total of 312 400 heavy vehicles were weighed in Namibia during 2015. Of the total vehicles weighed, 48 903 vehicles (15.7 %) were overloaded in terms of the

Table I. Summary table of the Namibian paved road network (NRA Road Referencing System: Network 10)

Road Network	Total (km)	Paved (km)	Percentage Paved (%)	Percentage Of Total Paved Network (%)
Trunk	4 778	4 778	100.0	63.1
Main	11 288	2 352	20.8	31.1
District	30 432	438	1.4	5.8
TOTAL	**46498**	**7568**		

legal limits by an average of 698 kg per vehicle, while 9 840 vehicles (3.1%) were chargeable. The overload control statistics for 2015 per weighbridge facility and for the top ten most common heavy vehicle configurations are summarised in Table II and Table III.

Table II. Summary table of the weighbridge overload control statistics for 2015

Locality	Number of Vehicles Weighed	LEGAL LIMITS		Average Overload (kg)	TOLERANCE LIMITS	
		Number of Vehicles Overloaded	Percentage Overloaded		Number of Vehicles Charged	Percentage Charged
Ariamsvlei	15 113	1 569	10.4	758	365	2.4
Aris	52 699	6 506	12.3	609	1 148	2.2
Brakwater	65 617	8 602	13.1	735	2 150	3.3
Gobabis	44 381	4 756	10.7	643	918	2.1
Katima	19 006	3 928	20.7	684	501	2.6
Noordoewer	6 598	439	6.7	502	45	0.7
Onhuno	22 782	2 211	9.7	758	520	2.3
Oshivelo	32 711	7 021	21.5	713	1 552	4.7
Walvis Bay	53 493	13 871	25.9	721	2 641	4.9
TOTAL	312 400	48 903	15.7	698	9 840	3.1

The NRA has 51 traffic count stations on the trunk road network, covering 4 778 km of the total road network and provided the volume of heavy vehicles in terms of EAADTT (Equivalent Annual Average Daily Truck Traffic) for each section of the trunk road network and the distribution of heavy vehicle volumes.

III. INPUT DATA

The developed methodology makes use of the following input data: pavement design data; heavy vehicle traffic count data; weighbridge data, climatic conditions and typical heavy vehicle design data.

Table III. Summary table of the top 10 vehicle configuration overload control statistics for 2015

Vehicle Class	Number of Vehicles Weighed	Number of Vehicles Overloaded	Percentage Overloaded	Average Overload (Kg)	No of Vehicles Chargeable	Percentage Chargeable
1222	131 996	20 579	15.6	892	6 454	4.9
123	79 012	20 253	25.6	505	1 266	1.6
11	43 443	1 510	3.5	677	668	1.5
12	23 828	2 443	10.3	498	519	2.2
122	10 717	943	8.8	731	171	1.6
112	4 722	189	4.0	684	85	1.8
1211	3 010	135	4.5	563	40	1.3
12211	2 368	783	33.1	462	52	2.2
22	1912	583	30.5	657	73	3.8
1121	1787	139	7.8	700	65	3.6

A. *Paved Road Network*

The Namibian trunk road network comprises 63% of the total paved network. On this network Namibia has 10 weighbridge facilities and 51 traffic count stations covering the entire paved trunk road network. Based on the data available, a detailed road wear cost estimation analysis was done for the trunk road network. The road wear caused by heavy vehicles on the paved main and district road networks was then extrapolated from the trunk road network to arrive at a conservative estimate of the total annual road wear cost for 2015.

B. *Pavement data*

Based on the pavement data received from the Roads Authority, 12 representative pavement structures were selected and design properties were allocated to each layer for the dry state. Pavement structures 7 and 10 are the most common pavement types. These two pavement structures consist of base layer materials G3 and G4, and subbase material G5. In cases where the pavement structure for a section was unknown, a weighted average of these two pavement types was used. To increase the accuracy of the analysis it is important to include all the different pavement structures of the entire network.

C. Climatic conditions

The mePADS software allows for the analysis of pavement performance in wet and dry climatic conditions by converting dry pavement properties to wet pavement properties. Namibia is a relatively dry country, with the highest rainfall in the northern parts of the country. Since pavement structure behaviour and bearing capacity are sensitive to climatic conditions, different wet and dry ratios were included in the analysis. A ratio of 90:10 for dry and wet states was recommended by the Namibia Roads Authority to represent the climatic conditions. This means that the road network is subjected to wet climatic conditions 10% of the time (in terms of geographical location and time of year).

D. Heavy vehicle traffic volumes

The mass distributions of the ten most common heavy vehicle configurations were determined based on the 2015 weighbridge data. In 2015, a total of 312 400 vehicles were weighed in Namibia at all the weighbridge facilities, giving a representative indication of the mass distribution of heavy vehicles on the network as shown in Fig. 2. A uniform mass distribution for each mass interval for all the weighbridges across the paved network was assumed for each of the different vehicle configurations.

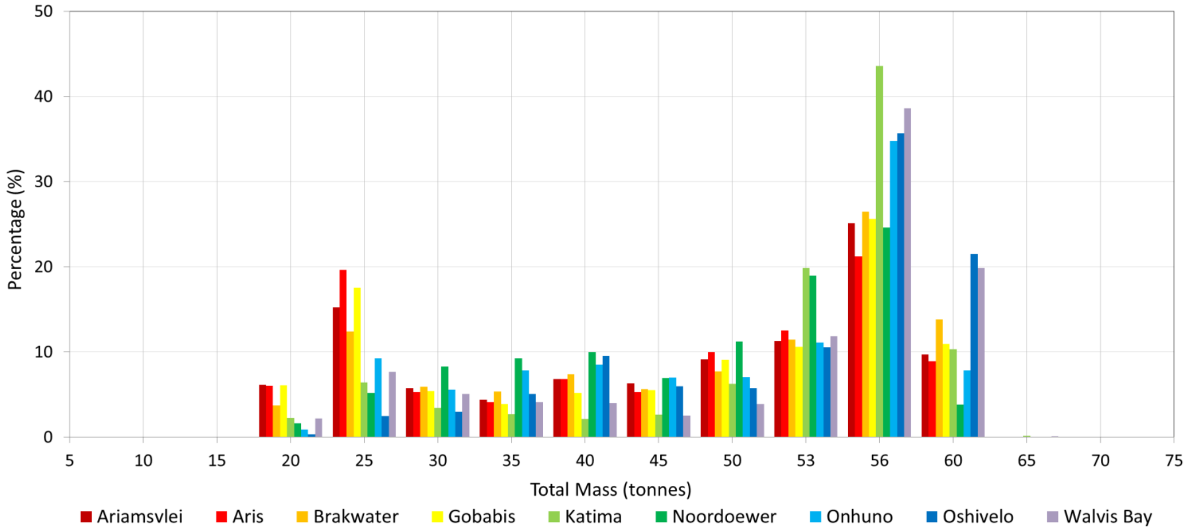

Fig. 2. Mass distribution of 1222 vehicles at different weighbridge facilities

The NRA traffic count system classifies heavy vehicles according to overall length as “Short” (4 to 10.8 m), “Medium” (10.8 to 16.8 m), and “Long” (longer than 16.8 m). The percentage distribution of these classifications was quantified for each section of the road network. In order to link traffic count and weighbridge data, the ten most common vehicle configurations, comprising 97% of all the heavy vehicles, were allocated to the three traffic count categories. In order to determine the number of vehicles per configuration per road section, the percentage split at the traffic count stations was used to distribute the heavy vehicle traffic in terms of “Short”, “Medium” and “Long” vehicles for each road section. The number of vehicles per traffic count class was then allocated to the vehicle configurations per class according to the distribution of heavy vehicle configurations derived from the weighbridge data. Fig. 3 and Fig. 4 show the percentage of heavy vehicle volumes in terms of different vehicle configurations and vehicle classes.

E. *Heavy vehicle designs*

General arrangement drawings of the ten most common vehicle configurations were obtained from trailer manufacturers. Examples of such drawings are shown in Fig. 5. These drawings were used as input parameters for the mePADS software.

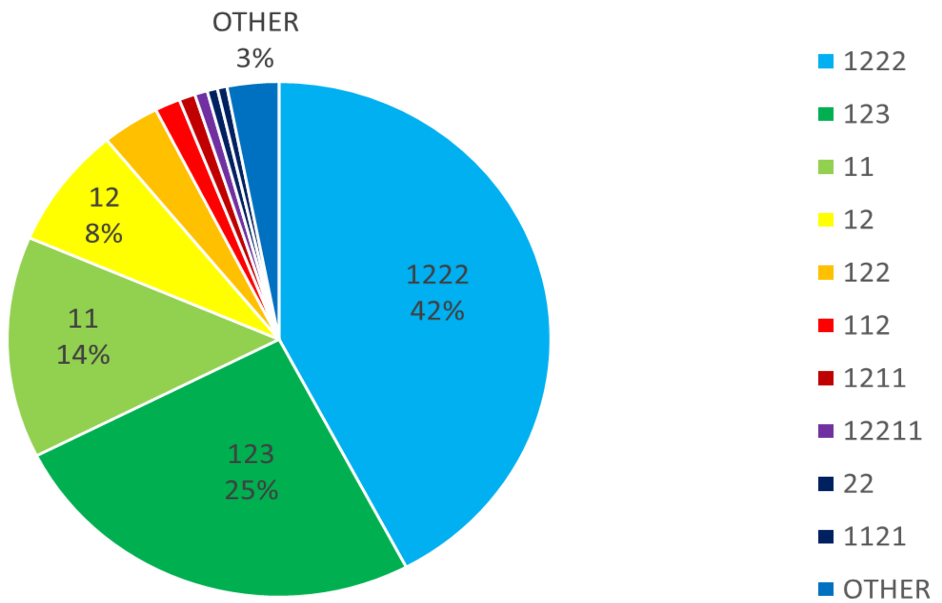

Fig. 3. Weighbridge distribution of heavy vehicle configurations

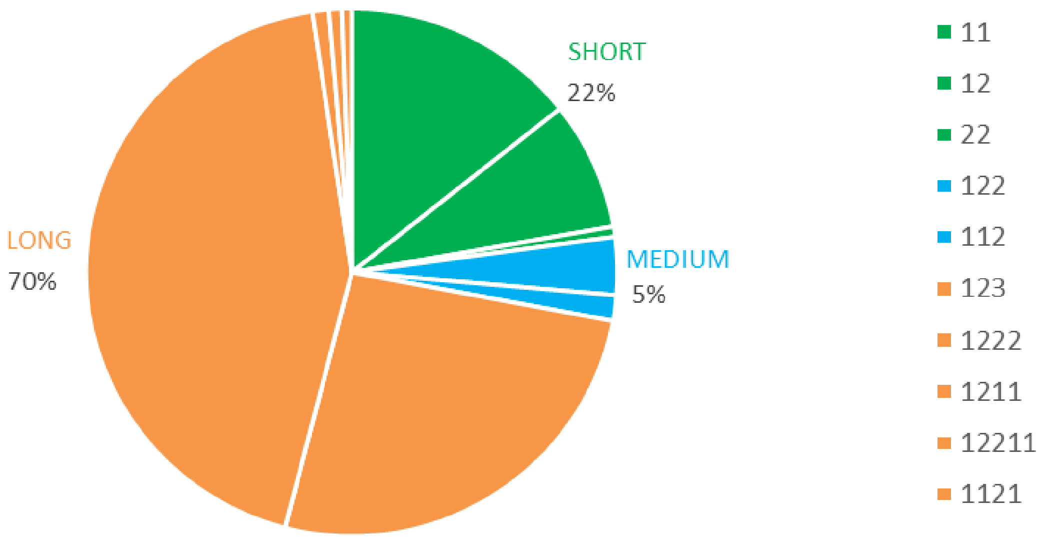

Fig. 4. Allocation of heavy vehicle configurations to the three traffic count classes

Based on surveys conducted on a sample group of operators in South Africa, typical tyre sizes were used for each vehicle configuration as indicated in Table IV. An average tyre inflation pressure of 700 kPa was used. Tyre sizes and inflation pressures were kept constant for simplification of each configuration.

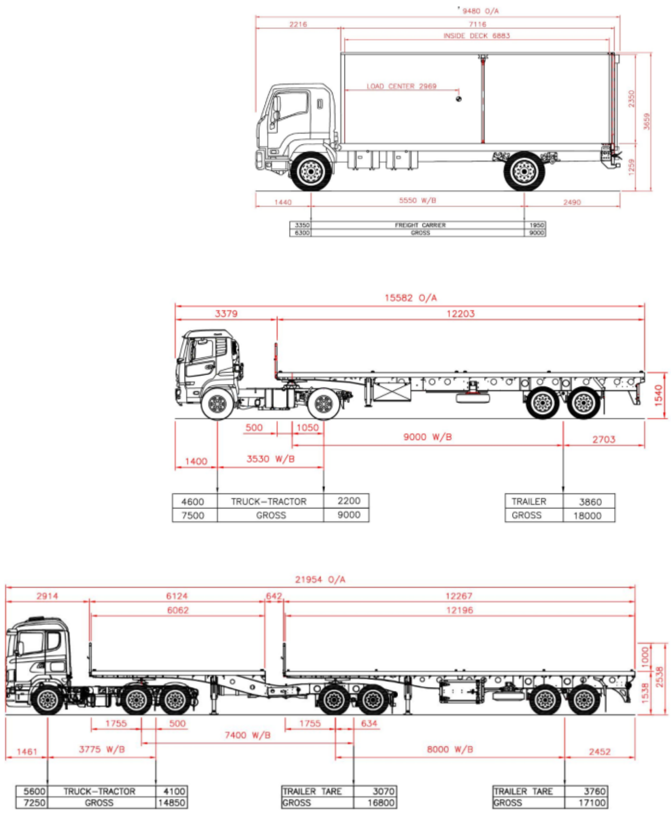

Fig. 5. Heavy vehicle design drawings

Table IV. Tyres Used For Each Vehicle Configuration

Vehicle Class	Steer Axle(s)	Drive Axle(s)	Trailer Axle(s)
11	11R22.5	11R22.5	N/A
12	315/80R22.5	315/80R22.5	N/A
22	315/80R22.5	315/80R22.5	N/A
112	315/80R22.5	315/80R22.5	315/80R22.5
122	315/80R22.5	315/80R22.5	315/80R22.5
123	315/80R22.5	315/80R22.5	315/80R22.5
1121	315/80R22.5	315/80R22.5	11R22.5
1211	315/80R22.5	315/80R22.5	315/80R22.5
1222	315/80R22.5	315/80R22.5	315/80R22.5
12211	315/80R22.5	315/80R22.5	315/80R22.5

The distribution of single and dual tyre axles, based on the 2015 weighbridge data, indicated that 96.5% of the axles (excluding steer axles) of the vehicles weighed in 2015 were fitted with dual tyres. Thus, for the purpose of this analysis, it was assumed that all the vehicles were fitted with dual tyres on all non-steering axles.

IV. METHODOLOGY

The core of the methodology is based on the South African mechanistic-empirical pavement design approach (TRH4) and includes empirical data from the Heavy Vehicle Simulator (HVS) accelerated pavement testing and Stress-in-Motion (SIM) field testing of typical pavement designs in southern Africa. A Load Equivalency Factor (LEF) is determined for each vehicle, which is primarily a function of the axle loads, wheel spacings, tyre sizes, tyre pressures and pavement properties [2].

The methodology used 2015 traffic data, which included static weighing data from 10 weighbridges and traffic count data from 51 traffic count stations. Weigh-in-Motion data could also have been used (preferable), but such data were not available. The weighbridge data were used to identify the 10 most common heavy vehicle classes (2-axle rigid up to a 7-axle combination) representing 97% of all heavy vehicles weighed. Representative mass distributions for each vehicle class were determined based on the weighbridge data. The 12 most common pavement designs used in Namibia were identified, of which two pavement types represent more than 80% of the paved road network. For each of the 10 vehicle classes, LEFs were calculated for 300 representative vehicles with a range of combination masses. Polynomial regression equations were then developed for each of the 10 common vehicle classes (based on the 300 representative LEFs per vehicle class) and the 12 pavement structures for both wet and dry climatic conditions i.e. 240 regression equations to calculate the LEF's of all vehicles weighed in 2015.

The heavy vehicle traffic count data were then used to calculate the estimated number of vehicle of each heavy vehicle class on each road link for the year. Based on the pavement types and the calculated number and mass distribution of the 10 common heavy vehicle classes for each road link, the total number of LEFs per road link was calculated for 2015.

The cost per LEF-km was determined using the Present Worth of Cost (PWOC) method as described in the South African TRH4 pavement design manual [3]. The construction cost was based on the reconstruction of the surfacing, base, sub-base, selected layers and subgrade.

A number of iterations of the road wear cost analysis for Namibia were done using different assumptions and input data. Sensitivity analyses were then conducted to ensure the results best represent conditions associated with Namibia.

V. RESULTS

A. *Total road wear cost*

The estimated annual cost of road wear per trunk road section, attributed to all heavy vehicles driving on each road section during 2015, was calculated by multiplying the average number of LEFs per vehicle class by the LEF unit cost (N$/LEF-km) for each pavement section and the heavy vehicle kilometres travelled by each vehicle configuration on that section of the road. The total estimated annual cost of road wear for the paved trunk road network was then calculated as the sum of the road wear cost per road section.

Four possible cost options were considered. For Options 1, 2 and 3, the reconstruction of different layers of the pavement structure was assumed, while Option 4 assumes a conservative fixed uniform cost range for all the pavement structures. Options 1, 2 and 3 are shown in Fig. 6. This is the total projected cost of a road, including construction and maintenance costs over the design life of the road. Details of the costs and assumptions included in each of the options are shown in Table V. A dry to wet climatic condition ratio of 90:10, was selected as the preferred costing approach and was endorsed by the Roads Authority. This option includes the construction and maintenance costs of the following pavement layers: surfacing; base; subbase; and all selected layers. The associated unit LEF costs for the 12 different pavement structures used in the final results were based on Option 2.

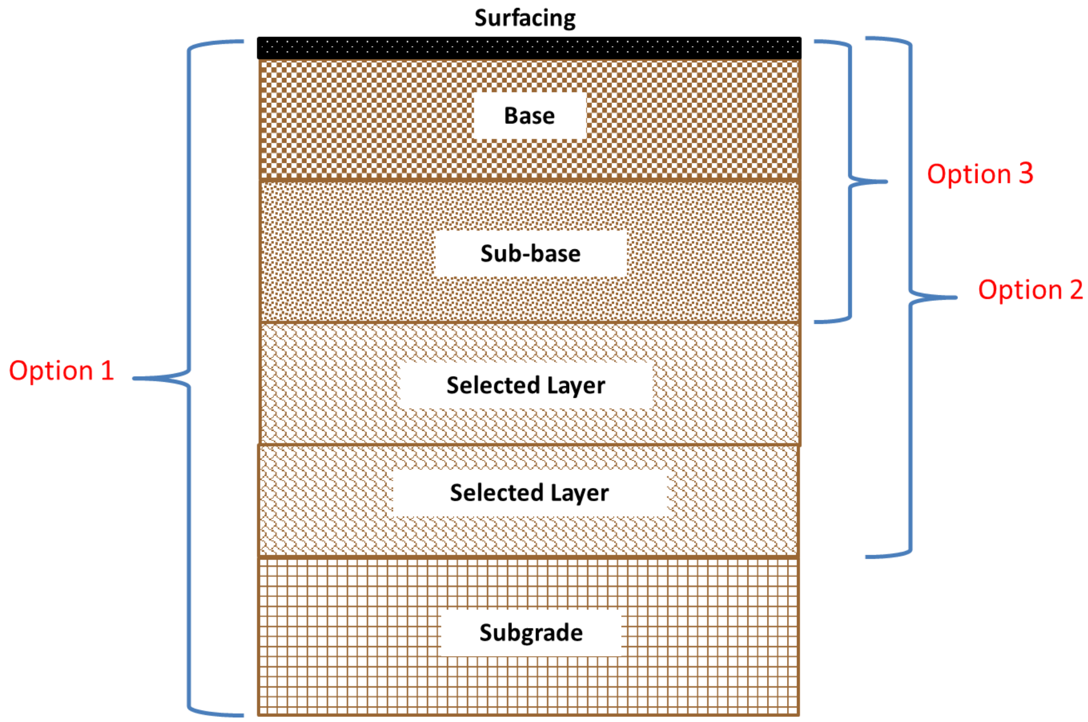

Fig. 6. Pavement structure

Based on the 2015 weighbridge and traffic count data, the annual cost of the road wear attributed to all the heavy vehicles travelling on the Namibian trunk road network was calculated to be approximately N$ 1.30 billion. This cost was calculated using the recommended unit LEF costs and a 90:10 dry to wet condition ratio and assuming the entire trunk network consists of two-lane highways. Assuming that the pavement structure and heavy vehicle traffic distributions on the paved main and district road networks are similar to those on the trunk road network, the annual road wear caused by heavy vehicles on the paved main and district road network is conservatively estimated at an additional N$ 760 million, giving a total estimated road wear cost of N$ 2.1 billion. More detailed traffic counts from a selection of sites on the paved main and district road networks would enable a more accurate estimate of the road wear cost on this part of the network.

	OPTION 1 (Most Conservative)	**OPTION 2 (Recommended)**	**OPTION 3 (Least Conservative)**	**OPTION 4**	
Pavement Structure	- Surfacing - Base - Sub-base - Selected layer - Selected layer - Subgrade	- Surfacing - Base - Sub-base - Selected layer - Selected layer	- Surfacing - Base - Sub-base	Uniform cost range for all the different pavement structures	
Additional Project Costs	• 15% P&G • 15% Prof Fees • 15% VAT			N/A	
Total cost of road wear for paved trunk road network (N$ billion)					
				N$ / LEF km	
				1.5	**1.7**
Climate Condition Ratio 80:20 (Dry:Wet)					
DRY	0.89	0.86	0.69	0.69	0.78
WET	0.71	0.68	0.54	0.71	0.80
TOTAL	**1.60**	**1.54**	**1.23**	**1.40**	**1.58**
Climate Condition Ratio 90:10 (Dry:Wet)					
DRY	1.01	0.96	0.78	0.78	0.88
WET	0.36	0.34	0.27	0.35	0.40
TOTAL	**1.37**	**1.30**	**1.05**	**1.13**	**1.28**

Table V. Summary table of cost variation and assumptions

B. *Overloaded road wear cost*

In addition to calculating the road wear caused by all heavy vehicles travelling on the network, an estimate of the road wear caused by overloaded heavy vehicles was done. The road wear cost of overloaded heavy vehicles was calculated using the same methodology. The overloaded vehicles were identified based on their actual and permissible axle masses and their overall combination mass.

The number of overloaded vehicles was quantified and the equivalent cost, if they were to be legally loaded, was calculated. The total number of overloaded vehicle kilometres travelled was multiplied by the same corresponding unit cost associated with the pavement, but multiplied by the LEF for a legal vehicle. This cost, which represents the road wear that would have been caused had these vehicles been legally loaded, was then subtracted from the total road wear cost caused by the overloaded vehicles in order to quantify the cost of road wear due to the overloads.

Approximately 7.4 million vehicles were identified as being overloaded during 2015, based on the traffic counts and the percentage of overloaded vehicles per vehicle class (from the weighbridge data). This corresponds to the 15.7% of heavy vehicles identified as overloaded from the 2015 weighbridge data. The total cost of road wear attributed to these overloaded vehicles on the trunk road network, using the recommended unit LEF costs and the 90:10 dry to wet condition ratio, was estimated to be approximately N$ 316 million. The road wear cost, should these vehicles have been legally loaded, is approximately N$ 299 million, resulting in a potential saving of N$ 17 million through improved overload control and regulation. Vehicle configuration 1222 is responsible for the largest percentage of the road wear costs (N$ 110 million of the N$ 316 million, which represents 35% of the N$ 17 million potential savings).

VI. CONCLUSIONS AND RECOMMENDATIONS

The aim of this study was to quantify the road wear caused by heavy vehicles on the Namibian paved road network. Based on the 2015 weighbridge and traffic count data, the annual cost of the road wear caused by all the heavy vehicles travelling on the trunk road network was calculated to be approximately N$ 1.30 billion. This cost was calculated using the recommended unit LEF costs and a 90:10 dry to wet condition ratio and assuming the entire trunk network consists of two-lane highways. A number of other scenarios were also analysed.

Assuming that the pavement structure and heavy vehicle traffic distributions on the paved main and district road networks are similar to that of the trunk road network, the annual road wear caused by heavy vehicles on the paved main and district road network is conservatively estimated at an additional N$ 760 million, giving a total estimated road wear cost of N$ 2.1 billion. More detailed traffic counts from a selection of sites on the paved main and district road networks would enable a more accurate estimate of the road wear cost on this part of the network.

In addition, a potential saving of N$ 17 million per annum on the trunk road network through improved overload control and regulation has been quantified and illustrates the continued need for ongoing overload control enforcement.

Although the results obtained from this study are considered reasonable, there are several recommendations for future work in order to improve the accuracy of the assessment. It is expected that the analysis accuracy will be improved by using weigh-in-motion data in order to obtain more representative axle mass data for the most common vehicle configurations. By using the weighbridge data, as was the case in this study, the possibility exists that the data may be skewed toward overloaded vehicles, resulting in higher road wear costs due to heavy vehicles.

The use of weigh-in-motion data would also be beneficial to increase the accuracy of the analysis as dynamic loading is known to produce increased road wear compared to static loads. Well-damped vehicles can produce 5-10% more road wear when moving compared to the static load case, while unfriendly heavy vehicles can produce increased road wear of 20-40% [4].

Various variables related to heavy vehicles were identified that have a significant effect on the LEF calculated for a specific vehicle class. These include the effect caused by the tyre inflation pressure and tyre sizes. This study used best practice values as obtained from industry surveys and experience to obtain a conservative estimation. Future models could however include information to consider the effect of these parameters. It is envisaged that this problem is ideally suited for machine learning techniques, but this would require large amounts of additional simulation data.

The road wear analysis approached used in this study requires knowledge of the pavement structures for the paved network. However, approximately 25% of the trunk road network was unclassified in terms of the pavement structure. To overcome this lack of information, a weighted average of the two most common pavement structures was assumed as the pavement structure for the unknown road pavement sections. The two most common pavement structures (pavement structures 7 and 10) represent approximately 80% of the classified trunk road network.

This study also assumed that the roads are newly built when bearing capacities are calculated using mePADS. The accuracy of the simulations could therefore be increased if the current condition (bearing capacities) of the roads are known. This would however require substantially more inspection, simulation and processing work.

A large variation in the cost per LEF-km was observed during this study, ranging from N$ 0.03 to N$ 12.40. It is recommended that for future studies, more comprehensive information should be obtained regarding construction costs for the different pavements as well as the exact pavement compositions and properties.

REFERENCES

[1] L. Kemp, A. Steenkamp and P. Nordengen, "Methodology for estimating the road wear costs of heavy vehicles on a road network," Rotterdam, 2018.

[2] M. De Beer, I. Sallie, Y. Van Rensburg and M. Kemp, "Load Equivalaency Factors (LEFs) for Abnormal Vehicles (AVs) and Mobile Cranes in South Africa Based on the Mechanistic -Emperical (M-E) Design Methodology," *Southern African Transport Conference (SATC),* 2009.

[3] DoT, Committee, Road Materials, "TRH4: Structural design of flexible pavements for interurban and rural roads," Department of Transport, Pretoria, 1996.

[4] NVF committee Vehicles and Transports, "Road Wear from Heavy Vehicles," Borlänge, Sweden, 2008.