WEIGHBRIDGE OR NO WEIGHBRIDGE

M M SLAVIK, Pr.Eng.

BKS (Pty) Ltd, P O Box 3173, Pretoria, 0001
Tel: 012 421-3724; martins@bks.co.za

ABSTRACT

The purpose of weighbridge is to control overloading and thus protect the road pavement. A weighbridge is economical if the saving in pavement maintenance is greater than the costs of the weighbridge. The saving depends on the length of road that the weighbridge controls. A measure of weighbridge economy - the so-called *break-even length* - has been introduced and derived from the equality of weighbridge costs and pavement maintenance savings. The break-even length depends on several factors of which the type of pavement, distribution of axle loads, magnitude of heavy-vehicle traffic, width of the pavement to be protected, cost of pavement maintenance, and the weighbridge operating cost are particularly important. For bituminous pavements the break-even length is about 50 km for volumes of heavy vehicles ranging from 200 per day to 3 000 per day. For volumes over 3 000 HV/day maintenance intervals become impractically short and a concrete pavement should be used instead of bituminous one. In case of a concrete pavement the break-even lengths are enormous – several thousands of kilometres – indicating that the cost of a weighbridge exceeds by far the savings in road maintenance. Although potentially beneficial from other points of view, a weighbridge on a concrete road cannot be justified in terms of reduced pavement maintenance.

1 INTRODUCTION

A static weighbridge is a device used to control overloading of vehicles and thus prevent untimely deterioration of pavement. For a weighbridge to be economical the pavement saving should be greater than the cost of the weighbridge. The magnitude of this saving depends on the pavement type and road length influenced by the weighbridge operation. The so-called *break-even length* was derived from the equality of pavement savings and weighbridge costs. The paper examines the influence of external factors (such as the magnitude of heavy-vehicle traffic, distribution of axle loads, weighbridge capital and maintenance costs, revenue from fines, and the frequency and cost of road maintenance) on the break-even length. The objective of the paper is to clarify the circumstances under which a weighbridge is economically justified.

A wide variety of load control facilities are used in South Africa. Four basic categories were considered:

- Small facilities such as the *lay-bys* on the N4 Maputo Corridor comprise of a single deck scale (3 m x 4 m), a holding yard for the correction of loads and minimum facilities to accommodate a guard. Weighing hardware and software are installed in a small bus called a *mobile load control unit* (MLCU). Such facilities are typically used as satellite stations in conjunction with larger establishments, such as *load or traffic control centres*. The cost of a lay-by facility is estimated to be in the order of R 15 million.
- Standard facilities are *load control centres* (LCC), such as the Komati, Machado and Middelburg. These also include screening facilities using *weigh-in-motion* (WIM)

Abstracts of the 31st Southern African Transport Conference (SATC 2012) 9-12 July 2012
Proceedings ISBN Number: 978-1-920017-53-8 Pretoria, South Africa
Produced by: Document Transformation Technologies cc Conference organised by: Conference Planners

equipment, a split 4-deck scale and buildings to accommodate the scalemaster, traffic police and administrative personnel. The cost of a standard facility can vary substantially depending on whether it includes dedicated screening lanes, automated number plate recognition, and additional infrastructure to accommodate satellite stations. A typical cost of a single facility is in the order of R 50 million.

- Large facilities are *traffic control centres* (TCC), such as the twin-weighbridges on the N3 freeway at Heidelberg and on the N1 freeway at Mantsole.
- Extra-large facilities are weighbridges such as those at Donkerhoek on the N4 East, Bapong on the N4 West and Beitbridge on the N1 North. In addition to the infrastructure of typical stations, these usually include *vehicle testing systems* (VTS), complex off-site screening facilities, tagging of vehicles and GPS tracking. The total cost of the recently completed Bapong TCC amounted to R 107.8 million.

The appropriate type and magnitude of overload control infrastructure depends primarily on the magnitude of truck traffic to be controlled, but also on the complexity of the road network and bypass routes.

2 INPUT DATA

Historical records of weighbridge costs, traffic data and pavement maintenance were examined in detail to obtain realistic input into the analysis. The effort is summarized in the following paragraphs.

2.1 Traffic

At present several national routes carry substantial amount of heavy-vehicle traffic. The volumes of average daily truck traffic (*ADTT*, heavy vehicles per day), as registered by electronic counting stations on various South African national roads in 2011, are shown in Table 1.

Table 1: Magnitude of heavy-vehicle traffic (ADTT) on major roads.

Road	**Locality**	**HV / day** *
N1	Pumulani	1554
N1	Mantsole	1418
N1	Kranskop	1442
N1	Pietersburg	1168
N3	Cedara	3322
N3	Hidcote	2893
N3	Roosboom	2420
N3	Van Reenen	2548
N3	Harrismith	2011
N3	Wilge	1812
N4 East	Bronkhorstspruit	741
N12	Witbank	1433
N4 East	Middelburg	1336
N4 East	Wonderfontein	1074
N4 East	Machado	849
N4 East	Kaapmuiden	808
N4 East	Komatipoort	549
N4 West	Zeerust	466
N4 West	Marikana	619
N4 West	Doornpoort	1201

* average per direction

Saving in pavement maintenance is achieved through longer periods between necessary interventions due to lighter axle loads when a weighbridge is present. Two traffic loading scenarios were explored, *with* and *without* a weighbridge. The actual distribution of axle loads measured by weigh-in-motion instrumentation in close proximity of the Heidelberg Northbound and Southbound weighbridges was used to represent the *with-weighbridge* situation. In the *no-weighbridge* situation the axle-load distribution was derived from the historical weigh-in-motion measurements done on the N3 National Road in both directions at two locations, namely Wilge and Van Reenen. The distributions are shown together in Figure 1. The green curve represents the combined Heidelberg weigh-in-motion measurements obtained in 2011, the red curve was derived from the combined data that were collected in 2002 (when the Heidelberg Traffic Control Centre had not yet influenced the traffic loading) at the four other sites.

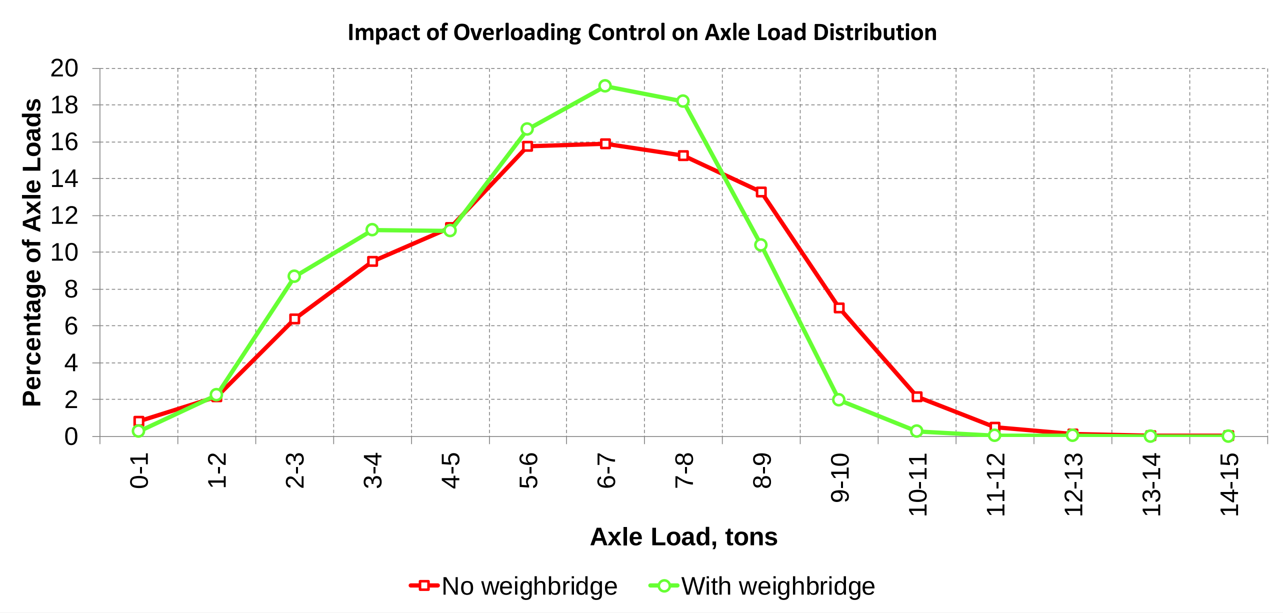

Figure 1: Axle-load distributions for the With-Weighbridge and No-Weighbridge scenarios.

Note the shift to the left from red to green; in the *with-weighbridge* scenario there are considerably fewer overloaded axles, but a higher number of axles in the 6 t to 8 t range. The key differences between the two traffic patterns are summarized in Table 2.

Table 2: Key differences between the two loading scenarios.

ITEM		**With WB**	**No WB**
Origin of data		HDB 2011	WLG & VNR 2002
Ave no. of axles per HV		5.364	5.280
Overloaded over grace		2.32%	15.85%
Ave tons per axle load		5.762	6.169
Bituminous pavement (Damage exponent = 4.2)	Ave E80 / axle	0.407	0.581
	Ave E80 / HV	2.182	3.068
Concrete pavement (Damage exponent = 4.5)	*Ave E80 / axle*	*0.397*	*0.585*
	Ave E80 / HV	*2.127*	*3.086*

In each loading scenario heavy-vehicle traffic magnitudes (Average Daily Truck Traffic, *ADTT*) were analysed, from 200 HV/day to 5 000 HV/day, as appropriate.

2.2 Pavement

The intervals between pavement maintenance interventions were modelled using the Cyrano mechanistic pavement design program (Slavik and Strauss, 2006) for bituminous pavements, and the cncPave software (Strauss, Slavik and Perrie, 2001) for continuously reinforced concrete pavements. The basic pavement parameters for the respective pavement types are given in Table 3.

Table 3a: Bituminous pavement parameters.

LAYER	Thickness	Stiffness	Poisson's ratio
Asphalt	40 mm	2000 Mpa	0.43
Base	150 mm	550 Mpa	0.30
Subbase	150 mm	1800 Mpa	0.20
Grade	150 mm	200 Mpa	0.35
Selected subgrade	-	80 Mpa	0.35

Table 3b: Concrete pavement parameters.

LAYER	Thickness	Stiffness
1	250 mm *****	4.2 Mpa ******
2	125 mm	1200 Mpa
3	150 mm	150 Mpa
4	150 mm	120Mpa
5	-	80 Mpa

***** Continuously reinforced with 20 mm diameter steel bars spaced at 140 mm

****** Flexural strength

The pavement reaches its terminal stage when it becomes dysfunctional. In case of bituminous pavement the loss of functionality – the ability to serve the users – is defined in terms of maximum tolerable values of cracked surface, depth of rutting, International Roughness Index (IRI) and pavement in distress (manifested as potholing, pumping, shoving, and/or unravelling). It was assumed that the pavement is left without intervention until it reaches the dysfunctional stage at which time it is reconstructed. In case of bituminous pavement the reconstruction consists of removing, reworking and compacting the top three layers – the asphalt, granular base and subbase.

In case of concrete pavement the loss of functionality is defined in terms of excessive area of shattered concrete, surface pumping, International Roughness Index and shrinkage crack spacing.

An intervention is triggered as soon as any one of the tolerances for the pavement is exceeded - these are shown in Tables 4a and 4b.

Table 4a: Bitumen pavement tolerances.

Variable	**Tolerance**
Cracked surface	Less than 30%
Depth of rut	Less than 15 mm
Int. Roughness Index	Less than 3.0 m/km
Pavement in distress	Less than 25%

Table 4b: Concrete pavement tolerances.

Variable	**Tolerance**
Shattered concrete	Less than 0.5 %
% surface pumping	Less than 5 %
Int. Roughness Index	Less than 3.0 m/km
Shrinkage crack spacing	Within 1.0 m – 2.5 m

An additional condition is that after a restorative intervention the pavement must become serviceable for at least *five* years.

The analyses showed that the critical parameters are International Roughness Index and the area of shattered concrete. In cases of bituminous pavement the terminal stage was caused by excessive IRI or cracking, whereas in cases of concrete pavement the terminal stage always occurred because the excessive area of shattered concrete, as shown in Table 5.

Table 5: Causes of pavement failure.

ADTT	**Bitumen pavement**		**Concrete pavement**	
	With WB	***No WB***	***With WB***	***No WB***
200 HV/day	IRI > 3.0	IRI > 3.0	SH > 0.5%	SH > 0.5%
500 HV/day				
1 000 HV/day				
1 500 HV/day		Crack > 30 %		
2 000 HV/day				
2 500 HV/day	Crack > 30 %			
3 000 HV/day				
3 500 HV/day				
4 000 HV/day				
4 500 HV/day				
5 000 HV/day				

<u>Note:</u>

IRI - International Roughness Index, m/km

Crack - Cracked surface, %

SH - Area of shattered concrete, % of surface

2.3 Weighbridge costs and revenues

Weighbridges have different versions, sizes and costs. Typical figures of sophisticated permanent weighbridges operating 24 hours a day seven days a week have been assumed and analysed in this paper.

The expenditure associated with a weighbridge is capital cost and operating cost. For completeness sake the amount of revenue accruing from *paid* fines was included in the analysis. The construction cost of the Bapong Traffic Control Centre, average annual operating costs of Mantsole Nortbound and Southbound weighbridges, and the revenues of the Heidelberg Southbound weighbridge were used in the study as representative figures. These are as follows:

Capital cost of the Bapong Traffic Control Centre	R107.8 million
Average 2011 operating cost of a Mantsole TCC weighbridge	R9.8 mill. p.a.
Paid fines generated by the Heidelberg Sb weighbridge in 2011	R1.5 mill. p.a.

In principle, the costs depend on the amount of traffic. Using the above information and data from other weighbridges the following generalized costs were derived:
Weighbridge capital cost, in R million: *ADTT / 30*
Weighbridge operating cost, in R million per annum: *ADTT / 300*
Revenue from paid fines, R million per annum: *ADTT / 1000*

3 PRESENT WORTH OF COSTS AND REVENUES

A 6 % per annum discount rate was used to calculate the *present worth* of benefits and costs occurring in the future.

The discount factor *f* applied in the calculations thus was:

$f = 1 / (1 + 6/100) = 0.9434$.

4 REPETITIVE RESTORATION OF PAVEMENT

It was assumed in both scenarios that the pavement is left without intervention until it reaches the terminal stage at which time the intervention takes place. In case of bituminous pavement the action consists of removing, reworking and compacting the top three layers – the asphalt, granular base and subbase. The unit cost of such reconstruction was taken at R400 per square metre. It was also assumed that the reconstructed road width is the space in which most heavy vehicles travel – a 2.5 m shoulder and a 3.5 m wide outer lane totalling 6.2 m. The reconstruction cost per one kilometre, *rc*, is thus:

$rc = R400/m^2 \times 6.2\ m \times 1\ 000\ m = R2.48$ million per kilometre of road.

In the case of continuously reinforced concrete pavement the intervention consists of repairing the areas of shattered concrete, the cost of which was estimated at R5 000 per square metre. Since only 0.5 % of the surface is shattered at the time of intervention the repair cost is:

$rc = R5\ 000/m^2 \times 0.5\ \% \times 6.2\ m \times 1\ 000\ m = R0.155$ million per kilometre of road.

If the above cost is incurred every y years then the present worth of the infinite series of such present worths, PWy, is given by the following formula

$$PWy = rc\frac{1}{1-f^{y}} \qquad \text{(Eq.1)}$$

The same principle applies to the recurrent annual weighbridge operating cost and revenue. The present worths thus obtained were used to calculate the road length over which a weighbridge should extend its influence to be profitable – the break-even length L_{be} .

$$L_{be} = \frac{Present\ worth\ of\ weighbridge\ costs}{Present\ worth\ of\ savings\ in\ pavement\ reconstruction}$$

Spreadsheets were used to accomplish the above task. As an example, the calculations for the ADTT of 2 000 HV/day arranged in a series of tables are shown in Table 6.

5 BREAK-EVEN LENGTHS

The break-even lengths calculated by the above method for various ADTTs are shown in Table 7.

The information in Table 7 is shown graphically in Figure 2 which makes the strong influence of traffic volume and pavement type on the break-even length very clear.

From Figure 2 it is evident that provision of a weighbridge on routes with bituminous pavement is justifiable in economic terms as long as its influence extends over as little as some 40 km of road. As the red curve shows, for concrete pavements the provision of a weighbridge is not economical – to be, the weighbridge would have to extend its influence over enormous distances in excess of 4 000 km, which is unrealistic.

Under high volumes of heavy-vehicle traffic, such as 3 000 HV per day, the bituminous pavement may require impractically frequent interventions. In this case an upgrade to concrete pavement becomes a necessity. This is apparent from the graph shown in Figure 3.

Should there be a weighbridge on a road with newly upgraded concrete pavement the weighbridge would become redundant as a pavement-saving device. However, even if not economically justified from the pavement maintenance point of view, the presence of a weighbridge may still be useful for ad-hoc weighing, general law-enforcement, check on vehicle roadworthiness, adherence to administrative procedures, and for the protection of not-yet-upgraded bituminous roads in the vicinity of the weighbridge.

Table 6: Example of the spreadsheet calculations for ADTT of 2 000 HV/day.

CONSTANTS		
Type of pavement	**Bitumen**	**Concrete**
Average Daily Truck Traffic, ADTT, HV/day	**2000**	**2000**
HV traffic type for the With-Weighbridge scenario	With WB	With WB
E80 per HV of the above traffic type	2.182	2.127
HV traffic type for the No-Weighbridge scenario	No WB	No WB
E80 per HV of the above traffic type	3.068	3.086
Discount rate, %p.a.	6.00	6.00
Cost of repair, R/m2	400.00	25.00
Weighbridge capital cost, R mill.	66.67	66.67
WB operating and maintenance cost, R mill. p.a.	6.67	6.67
Revenue from paid fines, R mill. p.a.	2.00	2.00
Width of pavement to be maintained, m	6.20	6.20
Discount factor	*0.9434*	*0.9434*
PW of With WB perpetual intervention cost, R/km	6516.38	167.37
PW of No-WB perpetual intervention cost, R/km	11031.99	194.96
With WB: Total E80 at the time of intervention, E80 million	13.10	69.45
Without WB: Total E80 at the time of intervention, E80 million	9.79	61.32
FAILURE TIME ANALYSIS		
Type of pavement	**Bitumen**	**Concrete**
Average Daily Truck Traffic, ADTT, HV/day	**2000**	**2000**
Failure time for the With-Weighbridge scenario, years	8.22	44.70
Perpetual repetition factor for the above	2.62757	1.07983
PW of the above perpetual repair, R/m2	1051.03	27.00
Failure time for the No Weighbridge scenario, years	4.37	27.20
Perpetual repetition factor for the above	4.44838	1.25781
Present worth of the perpetual repair, R/m2	1779.35	31.45
Difference between the two Present Worths, R/m2	728.32	4.45
Difference per one kilometre of road, R mill.	4.516	0.028
PW of weighbridge capital cost, R mill.	66.67	66.67
PW of weighbridge perpetual operating cost, R mill.	117.78	117.78
PW of perpetual paid fines, R mill.	35.33	35.33
Present Worth of the net weighbridge cost, R mill.	149.11	149.11
Break-even length, km	**33**	**5405**

Table 7: Break-even lengths for various volumes of heavy-vehicle traffic.

HV/day	Bitumen	Concrete
200	32 km	
500	42 km	
1000	41 km	
1500	36 km	6711 km
2000	33 km	5405 km
2500	32 km	4832 km
3000	33 km	4588 km
3500		4381 km
4000		4323 km
4500		4249 km
5000		4200 km

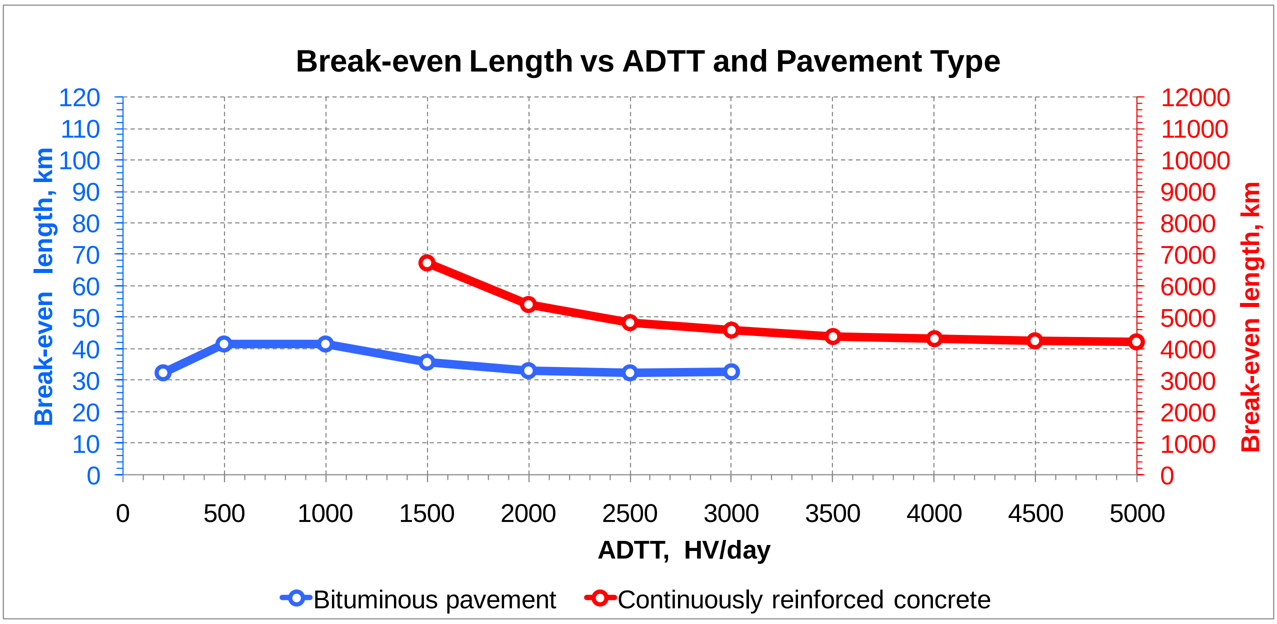

Figure 2: Relation between magnitude of HV traffic, pavement type and the break-even length.

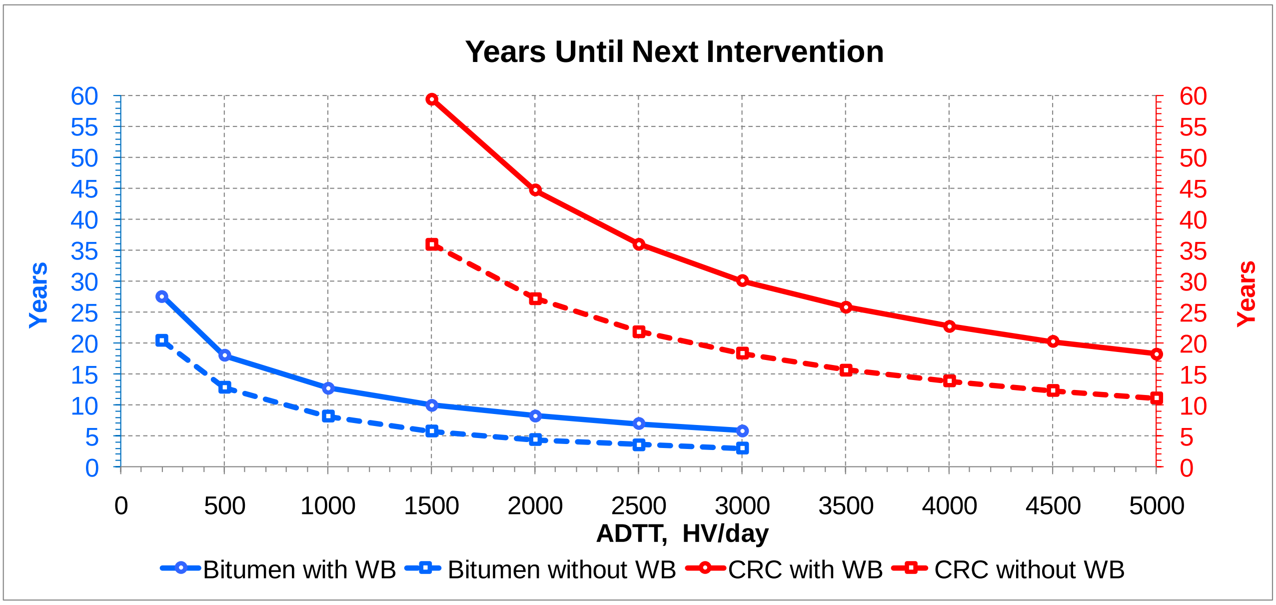

Figure 3: Years to next intervention.

8 CONCLUSION

If a weighbridge on a bituminous road can control overloading over some 40 km of a road, it is likely to be economically beneficial throughout the range of heavy-vehicle volumes from 200 HV/day to about 3 000 HV/day. The weighbridge costs will be justified by savings on road maintenance. In addition to pavement savings, the weighbridge would contribute to road safety by checks on roadworthiness of vehicles, promote fair competition among hauliers, and improve driving discipline by the continuous presence of traffic police.

If, however, bituminous pavement is replaced by a concrete pavement because of high volumes of heavy-vehicle traffic, there is no need for a weighbridge – its costs would be greater than savings in pavement maintenance. This is because the maintenance of a concrete pavement is relatively inexpensive and occurs at long intervals that are far in the future. Yet, if there already is a weighbridge on such a road it should be kept in operation for reasons other than reduced concrete-pavement maintenance.

9 ACKNOWLEDGEMENTS

The author wishes to express his gratitude to N3 Toll Concession for sponsoring the research and their permission to publish its outcome (Slavik and De Wet, 2012); to the South African National Road Agency, Trans African Concessions and Bakwena Platinum Corridor Concession for their cooperation, information and data provided.

10 REFERENCES

Slavik, MM and De Wet, GPD. *Economic viability of weighbridges*. Research report; Draft 2.1, N3 Toll Concession, April 2012.

Slavik, MM and Strauss, PJ. *Quantifying uncertainty in road pavement design using simulation.* Proceedings of the 25th South African Transport Conference. Pretoria, South Africa; 10 – 13 July 2006; pp. 26 – 34.

Strauss, PJ, Slavik, MM and Perrie, BD. *A mechanistically and risk based design method for concrete pavements in Southern Africa*. Proceedings of the 7th International Conference on Concrete Pavements. Orlando, Florida, September 2001, pp 133 – 146.