ANALYSIS METHODOLOGY FOR ESTIMATED COST OF INADEQUATE RIDING QUALITY IN SOUTH AFRICA

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ABSTRACT

Deteriorating road conditions can potentially have negative effects on road user costs. This is mainly due to the increased vibrations experienced by vehicles travelling on poor roads resulting in additional structural damages. The negative effects of deteriorating road conditions extend far beyond their impact on businesses, with deteriorating road conditions ultimately having a negative impact on the economy and competitiveness of a country. This paper discusses a method developed for the analysis of the national impact of inadequate riding quality on major freight corridors, and demonstrates the need to ensure that these corridors are maintained in a good condition.

1 INTRODUCTION

Deteriorating road conditions can potentially have many negative effects on the logistics operations and cost of businesses, with various studies showing that vehicles travelling on poor roads experience increased vibrations (Steyn et al., 2012; Jarimopas et al., 2005; Singh et al., 1991). This could result in additional structural damages to vehicles, leading to increased vehicle maintenance and repair costs and consequently higher company logistics costs.

The aim of this paper is to present a method for the analysis of the impact of inadequate riding quality on major freight corridors, and to demonstrate the need to ensure that these corridors are maintained in a good condition. The paper provides information on the latest available (2009) condition of the national and provincial road network in South Africa, as well as the major freight corridors in the country. It evaluates internationally accepted relationships between the road condition (in terms of riding quality) and road user costs such as the fuel consumption, tyre costs and vehicle damage due to uneven road surfaces. Finally, it demonstrates the use of the method of analysis to show the benefit of having a good quality road network available for the transportation of freight in the country (Steyn and Bean, 2013).

South Africa is in a fortunate position to have a pervasive road infrastructure network; however, maintaining the condition of this existing network generally appears problematic. Seeing that most freight is transported by road in South Africa, keeping the road network in a good condition is important to enable regional integration and enhance global competitiveness. In order to emphasise the importance of keeping the road infrastructure in a good condition, one should understand the effect that deteriorating road conditions can have on the logistics operations and economy of a region. Knowing what it will cost the economy when acceptable road conditions are not maintained in the country provides an indication of the potential gain that can be achieved when roads are kept in a good condition, supporting the understanding that the benefit of maintaining a road far outweighs the cost of not doing so.

2 SOUTH AFRICA'S ROAD NETWORK CONDITION

South Africa has a road network of approximately 746 978 km, of which 153 719 km is paved. The paved national roads covers around 16 170 km (under the jurisdiction of the South African National Roads Agency Limited (SANRAL)). In 2010, it was estimated that 26 per cent of the provincial road network (under the jurisdiction of nine provincial road departments) of 184 816 km is paved. Another 405 992 km of roads is under the jurisdiction of metros and municipalities and a further 140 000 km of gravel roads are not formally managed or maintained by any authority (Kannemeyer, 2010).

The condition of the South African national and provincial road network condition is defined in terms of the Visual Condition Index (VCI). The latest data on these conditions are provided in Bean and Steyn (2013). The VCI is a parameter used in South Africa to provide an overall measure of the condition of roads.

3 POTENTIAL EFFECTS OF DETERIORATING ROAD CONDITION

The potential negative effects of deteriorating road conditions can broadly be divided into six categories, i.e. effects on logistics management, vehicles, freight, road damage, the environment, and road safety (Bean and Steyn, 2013). Of particular interest to this study are the effects of deteriorating road conditions on vehicles which mainly manifest though increased vehicle damages (due to increased vibrations), increased tyre damages (and therefore tyre costs) and increased fuel consumption and the associated increase in fuel costs.

Although the roads agency / owner carries the construction and maintenance cost of road infrastructure, the road users incur even greater costs through Vehicle Operating Costs (VOCs) that are related to fuel and oil consumption, tyre wear, repair and maintenance, and depreciation.

A large body of research is available on the effects of pavement condition on VOCs and numerous models have been developed to estimate these effects. Chatti and Zaabar (2012) evaluated most of these available models and calibrated them for typical current US road users. Road user costs include VOCs, travel time delay, safety, comfort and convenience, and environmental impacts. Bennett and Greenwood (2003a) identified the different components of road user costs as incorporating costs associated with owning, operating, and maintaining a vehicle (including fuel consumption, oil and lubrication, tyre wear, repair and maintenance, depreciation, and license and insurance).

Common to most road user cost models is a road roughness indicator used to describe the condition of the road. Typically, the International Roughness Index (IRI) is used (Sayers et al., 1986). Road roughness describes the range of irregularities from surface texture through road unevenness, and it influences repair and maintenance costs, tyre use and market value and depreciation of a fleet. Various major road user cost models are identified by Chatti and Zaabar (2012) as follows:

- World Bank HDM III and HDM IV models (Bennett and Greenwood, 2003a, 2003b);
- Saskatchewan VOC models (Berthelot et al., 1996);
- British COBA VOC module (British Department of Transportation, 1993);
- Swedish VETO model (Hammarström and Karlsson, 1991);
- Australian NIMPAC VOC module (National Association of Australian State Road Authorities, 1978);
- New Zealand NZVOC (Bennett, 1989), and
- South African VOC models (du Plessis, 1989).

Most of these VOC models have benefited from the World Bank's HDM research. The HDM research dates back to a study by de Weille (1966) for the World Bank, which led to the development of the Highway Cost Model (Becker, 1972) which was over the years updated up to the most recent HDM IV model. The details of each of the models are not discussed in this paper, as the focus of the paper is on the application of the available models to a macro-level on SA freight corridors.

The most important cost components affected by road roughness is fuel consumption, vehicle repair and maintenance and tyre wear. Fuel consumption is mainly affected by road roughness with an increase of 1 m/km in IRI typically increasing the fuel consumption of heavy trucks by around 1 per cent at 96 km/h and around 2 per cent at 56 km/h. For vehicle repair and maintenance, the effect of road roughness only starts to become significant for IRI values of over 3 m/km, with an IRI increase up to 4 m/km which increase repair and maintenance cost by 10 per cent for heavy trucks. At an IRI of 5 m/km, this increase is 50 per cent for heavy trucks. An increase of 1 m/km in IRI increases the tyre wear of heavy trucks by 1 per cent at 88 km/h (Chatti and Zaabar, 2012).

The formulas in Chatti and Zaabar (2012) were developed to quantify the effects that deteriorating road quality can have on VOCs in the US. These formulas are used in the analysis of the potential effect of deteriorating road conditions on VOCs in South Africa, even though there may be some discrepancies between their results of the actual numbers in the South African situation. However, the basis of the formulas is similar to the HDMIV model and previous studies conducted in SA indicated that the quantum of these numbers is similar to South African values (Steyn et al, 2011). It should be noted that a process has been launched to calibrate these formulas specifically for South African conditions

4 METHODOLOGY

The methodology for the analysis of the potential effect of inadequate riding quality on VOCs is based on an analysis of the weighted riding quality of selected freight corridors in South Africa, and a comparison of the expected costs of three scenarios. These are the current mostly national road network, the same corridors but operations on the provincial networks for each of the corridors, and an analysis of the expected effect if the current condition on the national network is allowed to deteriorate.

The process calculated a weighted riding quality, based on the road conditions in Bean and Steyn (2013), for the 22 major freight corridors in South Africa (Figure 1) (Ittmann et al, 2011) to determine the expected condition of each of the corridors. This condition data were used together with road freight volumes on each of the corridors and the VOC relationships to calculate the fuel, tyre and additional vehicle damage costs. In order to indicate the severe effect that the current provincial network will have on the costs, and the major benefit that the availability of a high-class national route network can have on freight logistic costs in SA, an application of the method was conducted where the cost difference was calculated between using the national road network for the 22 corridors, compared to the provincial road network for the same corridors.

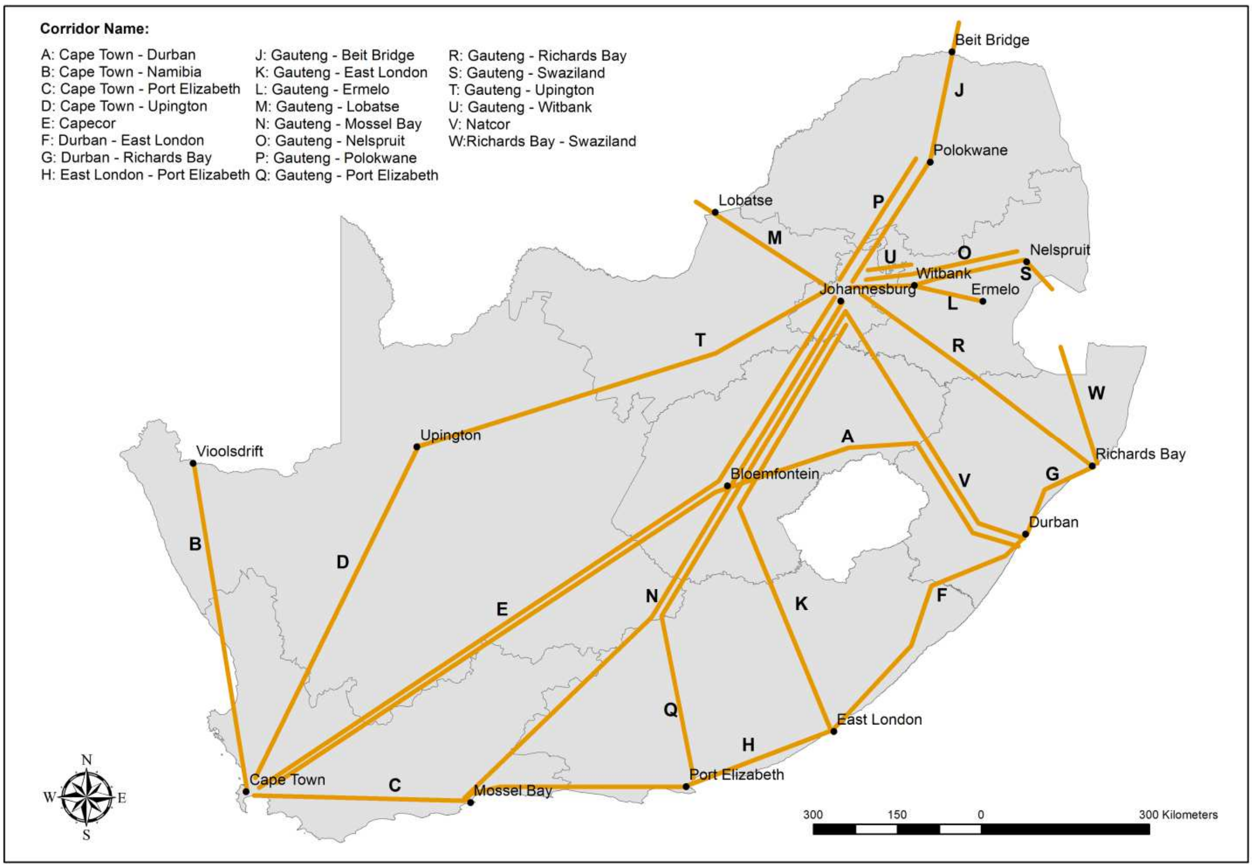

Figure 1: Main road freight corridors taken into account in the study (Steyn and Bean, 2013).

Data for the current conditions of the road network is based on the condition surveys conducted by each of the provinces and SANRAL. The VCI provides an evaluation of the road network in the five standard categories of Poor (P), Mediocre (M), Fair (F), Good (G) and Very Good (VG). In the analysis, the riding quality of the road network is required to calculate the various costs. As no complete dataset of riding quality is as yet available for the whole of the SA route network, the five categories were transformed into representative riding qualities using the values shown in Table 1. Using the selected riding quality values in Table 1 and the VCI data a weighted riding quality value was calculated for each authority's road network (Table 2).

Table 1: Comparison between condition categories and riding quality used in this paper.

Road condition index category	Average riding quality (IRI) [m/km]	Selected riding quality for analyses (IRI) [m/km]
Very Good	<1.0 m/km	1.0
Good	1.0 to 1.5 m/km	1.5
Fair	1.5 to 1.9 m/km	1.9
Mediocre	1.9 to 2.7 m/km	2.7

Poor	>2.7 m/km	6.0

Table 2: Weighted average riding qualities for nine provinces and national network (2009 data).

Authority	Weighted Average Riding Quality (IRI) [m/km]
SANRAL	1.68
Eastern Cape	2.20
Free State	3.87
Gauteng	1.85
Kwazulu Natal	2.91
Limpopo	1.64
Mpumalanga	2.50
North West	2.27
Northern Cape	1.89
Western Cape	2.12

Data were obtained showing the road length and freight volume (Simpson and Havenga, n.d.) for each of the 22 selected corridors. These data were used to calculate the expected number of similar trucks required on the route per year, assuming an average truck payload of 30 tonnes, providing the number of truck trips on each of the corridors per year (Table 3).

Using the route length for each of the corridors, the province through which the route travels and the weighted average riding quality for the province’s routes, the weighted average riding quality was calculated for each of the corridors. Based on this information, the various VOC equations and the current diesel and tyre price for trucks in South Africa, the annual VOCs for each of the corridors were calculated. Fuel cost of R 9.20/ l was used and an average tyre cost of R 5 000 per tyre. Regression equations were developed for the range of riding qualities encountered on the South African network (equations shown in Table 4).

Table 3: Freight volume, route length and truck numbers per corridor

Corridor	Annual freight volume on road [Millions ton-km]	Distance [km]	Annual number of trucks
Cape Town–Durban	11 071	1 344	274 608
Cape Town–Namibia	359	450	26 593
Cape Town–Port Elizabeth	2 753	566	162 275
Cape Town–Upington	1 716	871	65 672
Capecor	26 477	835	1 056 579
Durban–East London	4 154	482	287 275
Durban–Richardsbay	1 520	304	166 510
East London–Port Elizabeth	2 420	424	190 476
Gauteng–Beitbridge	2 696	490	183 551
Gauteng–East London	2 954	929	105 992
Gauteng–Ermelo	695	480	48 264
Gauteng–Lobatse	1 928	315	204 114
Gauteng–Mosselbay	1 999	1 182	56 373
Gauteng–Nelspruit	2 056	552	124 155
Gauteng–Polokwane	2 614	271	321 982
Gauteng–Port Elizabeth	4 457	683	217 457
Gauteng–Richardsbay	3 299	445	246 931
Gauteng–Swaziland	1 024	476	71 709
Gauteng–Upington	3 459	649	177 704
Gauteng–Witbank	3 122	166	627 223
Natcor	20 381	423	1 604 833
Richardsbay–Swaziland	366	617	19 773

Table 4: Regression equations used in data analysis.

PARAMETER	EQUATION	STANDARD ERROR
Fuel consumption [mL / km]	FC = 1 661.353 IRI + 7.787	0.0109
Tyre wear [percentage / km]	TW = 0.00069 IRI $+6.979 \times 10^{6}$	1.05275E-06
Repair and maintenance cost [R / km] - damage from vibrations only	RMC = 0.0969 IRI + 0.4039	0.07324

5 ANALYSIS APPLICATION

To investigate the potential effect of road conditions on fuel, tyre and vehicle maintenance and repair costs, an analysis was done on the 22 main road freight corridors in SA as shown in Figure 1. The analysis focused on freight transportation and determined the total fuel consumption, tyre cost and annual vehicle repair and maintenance cost for freight transported on the corridors under consideration. The comparison between the national and provincial route options are shown in Table 5. The results suggest a possible increase of 28 864 kL in fuel consumption, R 28,5 million in tyre costs and R 359 million in additional vehicle repair and maintenance costs. This translates to around 0.03 per cent of

Gross Domestic Product (GDP) or 16 per cent of the country's provincial road transport budget for the 2010/11 financial year.

The method has also been applied to a wider selection of analysis options in Steyn and Bean (2013).

Table 5: Comparison between traffic flowing on national and provincial road networks through 22 corridors.

Freight transport total	National road network	Provincial road network	Difference	% increase from actual
Total annual fuel consumption for all corridors	5 669 502 kL	5 698 366 kL	28 864 kL	0.51%
Total annual fuel cost (based on R 9.2/L)	R 52,159 billion	R 52,425 billion	R 265,548 million	0.51%
Total annual tyre cost for all corridors	R 2,629 billion	R 2,657 billion	R 28,456 million	1.08%
Total annual repair and maintenance cost for all corridors – damage caused by vibrations only	R 1,958 billion	R 2,316 billion	R 359 million	18.34%

6 CONCLUSIONS AND RECOMMENDATIONS

The effects that poor road conditions have on a country can be significant and this article investigated the potential effects that deteriorating road conditions could have on the economy of South Africa. It presents a method to determine the potential effect on selected road user costs of changes in riding quality for a road network. Results of an analysis on the 22 main road freight corridors in the country indicate an increase of 28 864 kL in fuel consumption, R 28,5 million in tyre costs and R 359 million increase in additional vehicle repair and maintenance costs when comparing the national road network conditions with those of the provincial road network. This supports the notion that it is important to maintain good riding quality on a road network in order to avoid the additional costs associated with transporting freight on poor condition roads.

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