INVESTIGATING THE ENVIRONMENTAL COSTS OF DETERIORATING ROAD CONDITIONS IN SOUTH AFRICA

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ABSTRACT

The potential environmental impacts of deteriorating road conditions on logistics systems and the national economy have not received significant attention. This study gives an estimate of the potential environmental costs of deteriorating road network conditions in South Africa. This paper is an extension of past studies dealing with the potential effects of deteriorating road conditions in South Africa and focuses on comparing the environmental impacts of freight transportation on the national and provincial road networks. The International Panel on Climate Change (IPCC) guidelines for estimating carbon dioxide emissions from vehicles was used to determine the potential environmental costs. Preliminary calculations show increased environmental costs on the provincial road network when used for freight transportation as compared to the national road network. This is because the national road network is in a much better condition compared to the provincial road network. Finally, recommendations for future enhancements of the methodology to quantify the environmental impacts of deteriorating road conditions are given.

Keywords: road network, environmental costs, externality, road conditions

1. INTRODUCTION AND BACKGROUND

This study aims to quantify the potential environmental costs of deteriorating road conditions in South Africa. The idea is to consider the effect on the externality costs of operating vehicles on a very good road network compared to a poor one. According to Bartholomeu and Filho (2008) road conditions have never been considered as a determinant of vehicle emissions. Most of the studies use specific software to determine emissions but these programs are always linked to default values from North America and European fleets. Therefore they are not a true reflection of local conditions in most of the cases. It is important to understand the potential effects of deteriorating road conditions because these effects also influence the country’s economy and result in increased logistics costs. A number of studies have been carried out in South Africa in the past years to try and understand the effects of deteriorating road conditions on logistics costs and the economy (Steyn et al, 2009; Steyn and Bean, 2010; Steyn and Bean, 2013; Bean and Steyn, 2013).

There is also a relationship between the condition of the road infrastructure and the economic development of a region or province (Mashoko, 2013). These studies identify the potential impacts of poor road network conditions on logistics operations and cost. Some of the impacts of a poor condition road network are summarised in Figure 1 (Steyn et al., 2009).

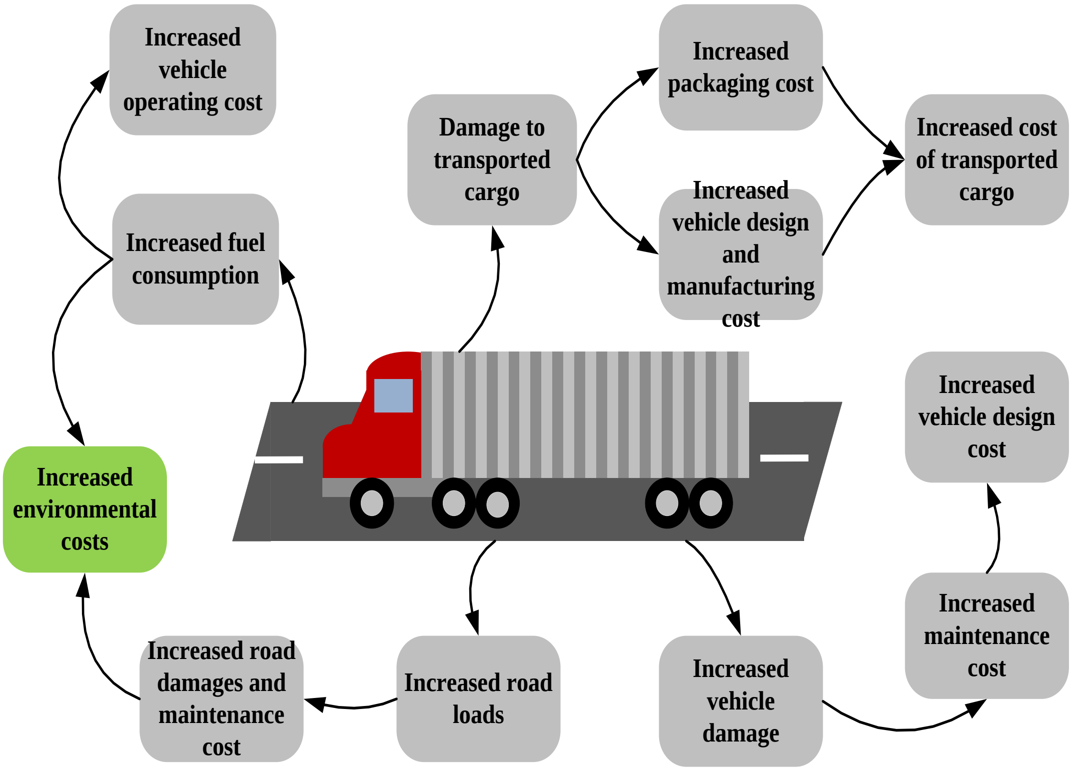

Figure 1: Potential Effects on Bad Road Quality on the Economy (Steyn et al. 2009).

Although many previous studies have already considered the impacts of road network conditions on vehicle operating cost and the cost of transported cargo, the impacts on environmental cost were largely unexplored. This study therefore aims to give some insights into the environmental costs of deteriorating road conditions.

1.1 The South Africa Road Network Condition

The overall road network length in South Africa is approximately 747 000 km of which an estimated 153 719 km is paved. The paved national roads are under the jurisdiction of the South African National Roads Agency Limited (SANRAL) and covers around 16 170 km. South Africa's provincial roads are under the jurisdiction of nine provincial road departments. It is estimated that 26 per cent of the country's current provincial network of 184 816 km is paved. Of the remaining roads, 405 992 km is under the jurisdiction of metros and municipalities and an estimated 140 000 km of gravel roads are currently not formally managed or maintained by any authority (Kannemeyer, 2010). An overview of the South African national and provincial road network is determined by means of a Visual Condition Index and is presented in Figure 2.

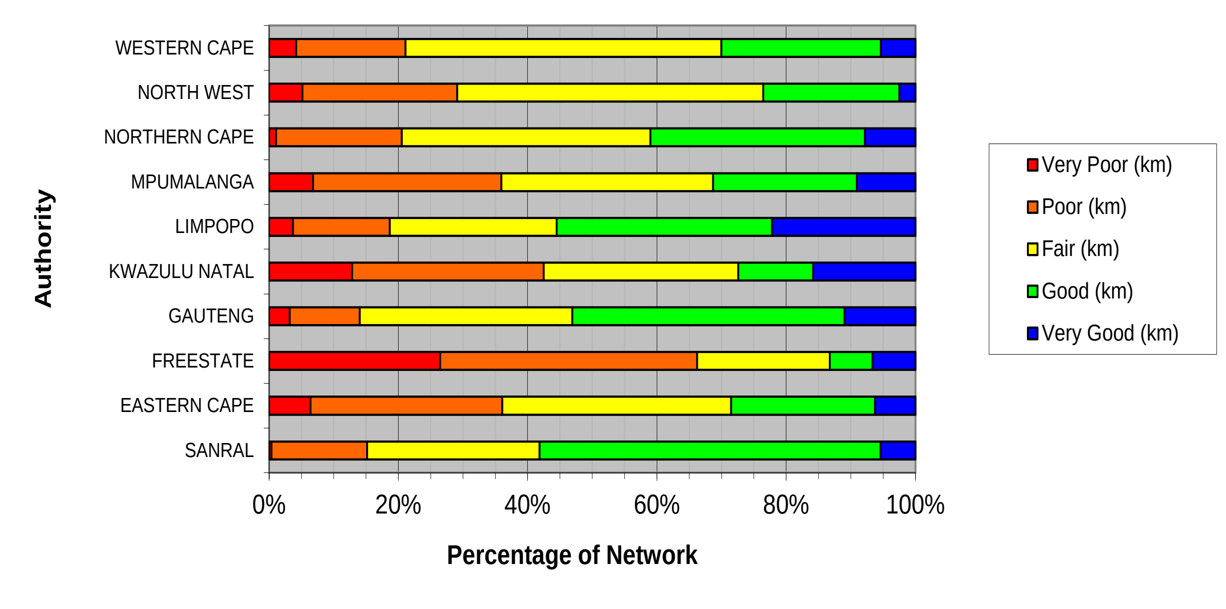

Figure 2: Summary of South African Road Network Condition (Kannemeyer, 2010).

1.2 Externality Costs

A negative externality is a spill over of an economic transaction that negatively impacts a party that is not directly involved in the transaction (Public Econ Wikispaces, 2013). The first party bears no costs for their impact on society while the second party receives no benefits from being impacted. Externality costs are considered as one source of market inefficiency and they occur whenever a production process has an identified positive or negative effect to other (Bartholomeu and Filho, 2008).

Greenhouse Gas (GHG) emissions from road transport result in externalities such as global warming and climate change. Therefore increases in GHG emissions as a result of poor road network conditions influence the impacts of these externalities. In addition, increases in GHG emissions result in increased socio-economic challenges to the communities around the road networks (OECD, 2008). Therefore it is necessary to understand the source of some of these externalities so that appropriate measures can be taken to reduce their impact.

1.3 Environmental Impacts of Deteriorating Road Quality

Vehicle emissions are affected by traffic characteristics such as average speed, types of vehicles, number of lanes, traffic volume and road condition. Vehicle emissions also depend on the age of the vehicle, the technology it represents, its weight class and other driving characteristics like load speed and driving technique (Bartholomeu and Filho, 2008). Poor road conditions can lead to accidents which increase congestion on the road thereby resulting in more emissions to the environment. Poor road conditions also have a direct effect on the driving characteristics and techniques used by the drivers to deal with the conditions. This also have a negative impact on fuel economy resulting in more emissions to the environment when compared to a road in better condition.

RESEARCH METHODOLOGY

To quantify the environmental costs of freight transportation on poor condition roads, fuel-based or distance-based methodologies can be used to calculate CO_2 emissions. The fuel-based approach makes use of the CO_2 emission factor for each fuel type in order to quantify the emissions during transportation. The fuel consumption is multiplied by the CO_2 emission factor to estimate the total emissions (GHG Protocol, 2005). The distance based methodology calculates emissions based on distance based emission factors. The activity data for this approach can be tonne-kilometres or vehicle kilometres in the case of freight transportation (GHG Protocol, 2005). According to the GHG Protocol (2005) the fuel based method is preferred to the distance based method because data on fuel are generally more reliable. Therefore the fuel based method is adopted in this study to compare CO_2 emissions from poor condition roads to other roads in a very good condition.

2.1 Calculating Environmental Impacts

In this study two set of calculations were carried out to investigate the effect of road roughness (based on the International Roughness Index (IRI)) on the environment through increased emissions. The first one involves calculating the GHG emission in kg/km for vehicles travelling in roads of different road roughness at four pre-determined speeds. The speeds are 60, 80, 100 and 120 km/h. The reason for taking the speed into account is to show how vehicle speed affects its emissions.

The second set of calculations was used to estimate the amount of GHG emissions that can be emitted from roads of different roughness. This is based on the differences in fuel consumption over road conditions for the national road network and the provincial road network. The information used was extracted from Steyn and Bean, (2013) and is shown in Table 1.

Table 1: Comparisons between Traffic on National and Provincial Road Networks (Steyn and Bean, 2013).

Freight Transport Total	National Road network	Provincial Road network	Difference	% increase from actual
Total annual fuel consumption for all corridors[1]	5 669 502 kL	5 698 366 kL	28 864 kL	0.51%
Total Annual Fuel Cost (Based on R 12.91/L)[2]	R 73.19 billion	R73.57 billion	R372.63 million	0.51%

[1] Figures adopted from Steyn and Bean, 2013, Table 5
[2] Figures adopted from Steyn and Bean, 2013, Table 5 updated to reflect latest fuel prices

In this case the environmental variable under consideration is the amount of carbon dioxide emitted per kilometre driven over the different road conditions in the freight corridors used in the study of Steyn and Bean (2013). The diesel emission factor was used for this study. It was assumed that combustion is complete and that all the fuel is converted to carbon dioxide during the combustion process. In addition, it was assumed that carbon monoxide (CO) and non-methane volatile organic compounds (NMVOC) are all converted into carbon dioxide in the atmosphere. A diesel carbon emission factor of 2.70 kg per litre of fuel used was adopted for this study (Urban Earth, 2011).

The amount of CO_2 emitted is calculated using the formula:

$$\boldsymbol{E = SFC \times FE} \qquad \textbf{\textit{(1)}}$$

Where:

E = Total emissions.

SFC = the amount of a fuel consumed for trucks travelling over the national or provincial road network.

FE = the fuel CO_2 emission factor for Diesel (2.70 kg per litre)

This formula was applied to the information in Table 1.

3 RESULTS

This section summarises the two sets of results that show the effect of road roughness on GHG emissions and the estimate of total GHG emissions in two different road network conditions.

3.1 Effect of Road roughness on GHG emissions

The results of calculations done at different speeds provide an indication of the relationship between the road roughness and the amount of GHG emissions at different speeds. As expected the amount of emissions increased when speed increased.

However, the main focus of this study was to understand the relationship between road roughness, based on the International Roughness Index (IRI), and GHG emissions. The table below shows the GHG emissions at four different speeds against the road roughness at four levels that are defined as follows:

- Very good with an IRI of 1 m/km;
- SA average which is the average weighted IRI for South Africa based on road conditions in all South African provinces with an IRI value of 2.1 m/km;
- Poor with an IRI of 2.7 m/km; and
- Very poor with an IRI of 8.1 m/km.

The results of the analysis are as shown in Table 2.

Table 2: Effect of Road Roughness and GHG Emissions at Different Speeds

		GHG Emissions (kg/km)			
	Weighted IRI (m/km)	60 km/h	80 km/h	100 km/h	120 km/h
Very good	1	0.68	0.94	1.28	1.76
SA Average	2.1	0.68	0.94	1.28	1.76
Poor	2.7	0.68	0.94	1.29	1.77
Very poor	8.1	0.93	1.19	1.57	2.13

The results show that there is an increase in GHG emissions when road roughness increases, but these increases are not very significant for small increases in road roughness. For example, at 100 km/h, a road roughness of 1 m/km results in 1.28 kg/km GHG emissions whereas for road roughness of 2.7 m/km at the same speed, results in emissions of 1.29 kg/km. This is an increase of 10 g/km. On the other hand a road roughness of 8.1 m/km which corresponds to a very poor road has a GHG emission of 1.57 kg/km at an average speed of 100 km/h. This is a significant increase in the emissions produced when the road condition is very poor. The speed at 120 km/h was used for illustration purposes even though in normal conditions it might be impossible to drive at such a speed in such road conditions. The scenario explained above is highlighted in Figure 3.

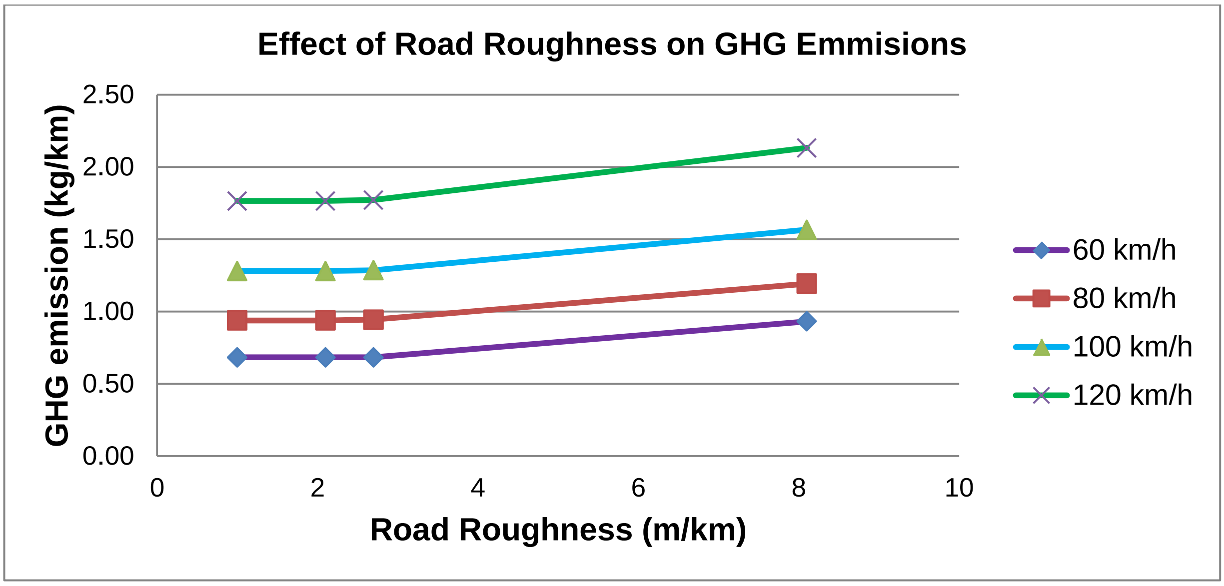

Figure 3: Effect of road roughness on GHG Emissions at Different Speeds

Table 3 shows the GHG emissions for South Africa's national and provincial road networks.

Table 3: Effect of Road Roughness on GHG Emissions for SA Road Network

		GHG Emissions (kg/km)			
	Weighted IRI	60 km/h	80 km/h	100 km/h	120 km/h
Limpopo	1.64	0.68	0.94	1.28	1.76
SANRAL	1.68	0.68	0.94	1.28	1.76
Gauteng	1.85	0.68	0.94	1.28	1.76
Northern Cape	1.89	0.68	0.94	1.28	1.76
Western Cape	2.12	0.68	0.94	1.28	1.76
Eastern Cape	2.2	0.68	0.94	1.28	1.76
North West	2.27	0.68	0.94	1.28	1.76
Mpumalanga	2.5	0.68	0.95	1.29	1.77
KZN	2.91	0.68	0.95	1.29	1.77
Free State	3.7	0.71	0.96	1.31	1.80

The table indicate, as expected, that road networks in a worse condition have higher GHG emissions per kilometre. Even though these increases may appear small per kilometre, the impact will be much more significant when considering the annual traffic volumes on these roads.

3.2 Annual Carbon Dioxide Emissions

The following section gives an estimate of the extra carbon dioxide emissions released into the atmosphere as a result of travelling on the provincial road network when compared to the national road. This information is based on an investigation carried out by Steyn and Bean (2013) to estimate the potential effect of road conditions on fuel, tyre and vehicle maintenance and repair costs. This analysis was done on the 22 main road freight corridors in South Africa. 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 investigated. An extract of the comparison between the national and provincial route options is shown in Table 4. The table shows an increase in fuel consumed when travelling on the provincial road network compared to the national road network. Travelling on the provincial road network consumes 28 864 kL more fuel than travelling on the national road network for the same amount of traffic. The extra fuel consumed results in increased CO_2 emissions.

To investigate this increase, the extra fuel consumed was converted to CO_2 emissions using the emission factor per litre of diesel consumed. The table shows that travelling on the provincial road network increases the fuel consumption, fuel cost and the carbon dioxide emissions by 0.51 per cent. Improving the road conditions of the provincial road network to the same level as the national network will reduce the amount of CO_2 emitted by almost 80 000 tonnes.

Table 4: Comparison between Provincial and National Road Network

Freight Transport Total	**National Road network**	**Provincial Road network**	**Difference**	**% increase from actual**
Total Annual Fuel consumption for all corridors[3]	5 669 502 kL	5 698 366 kL	28 864 kL	0.51%
Total Annual Fuel Cost (Based on R 12.91/L)[4]	R 73.19 billion	R73.57 billion	R372.63 million	0.51%
Total Annual CO_2 Emissions	15 308 kilo tonnes	15386 kilo tonnes	77 932 tonnes	0.51%

[3] Figures adopted from Bean and Steyn, 2013, Table 5
[4] Figures adopted from Bean and Steyn, 2013, Table 5 updated to reflect latest fuel prices

3.2 Recommendations

Although the study managed to show the effect of road conditions on the environment there are ways in which the results can be improved in future. It is recommended that empirical methods of data collection be adopted to improve the accuracy of the results. This would involve collecting data from trials in which trucks equipped with data collecting devices are driven over different road network conditions. This would enable the collection of information such as average speed, maximum speed, trip duration, fuel consumption, weight of load and the type of route. This information is important in estimating the GHG emissions from the trucks. This would mean that all the trucks in the experiment would have to travel in same conditions that is, the same load, same time for the trip, in the same weather conditions and the same drivers. This was not possible in this study due to limited time and the costs involved in such an extensive study.

4 CONCLUSION

The aim of the study was to show the effect of road conditions on the environment in terms of increased GHG emissions. The study shows that GHG emissions increase with an increase in speed and also with an increase in road roughness. Although the increase is small for smaller increases in road roughness the analysis shows that the effect is very significant if the road conditions are very poor. The increase in fuel needed to travel over the provincial road network as compared to the national road network is also an indication of the effect of road conditions on GHG emissions. This increase in fuel consumed translates to an increase in GHG emissions. About 80 000 tonnes more of CO_2 are emitted into the atmosphere when travelling on the provincial road network. This shows that there are environmental benefits of having well maintained roads. The most important thing is that well maintained roads have other economic benefits in addition to the environmental benefits highlighted. This shows that if the effects of transport on climate change are to be reduced an improvement in road network conditions will also help to achieve this.

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