RESOURCE CONSUMPTION ANALYSIS IN THE GOVERNANCE OF TRANSPORT INFRASTRUCTURE IN A DEVELOPING COUNTRY

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Abstract

This paper provides a detailed estimate of fuel consumption rates for six representative vehicle classes on different types of rural roads in South Africa for use in macroscopic analysis during road planning. The vehicle classes are: Cars, light petrol-driven vehicles other than cars, light goods vehicles, medium-sized goods vehicles, heavy goods vehicles and buses. Measured and estimated fuel consumption rates on different paved and unpaved rural road types in flat, rolling and mountainous terrain are supplied.

Keywords: Fuel Consumption, Rural Roads, Road Planning, Road Vehicle Classes, Topography

1. INTRODUCTION

One of the aims of road improvement projects and the construction of new roads is to reduce road user costs, which are vehicle running costs, value of travellers' time and accident costs. Vehicle running costs include fuel consumption, tyre wear, oil consumption, maintenance costs and capital cost. To enable analysts to assess the savings potential of a planned road objectively, it is essential to calculate road user costs realistically. Fuel consumption constitutes the largest single vehicle running cost item, and in many cases also the largest cost item of total road transport operations. It amounts to between 25% and 35% of the total cost of road transport operations (Road Freight Association, 2015).

2. THE INFLUENCE OF RURAL TRAVEL CONDITIONS ON VEHICLE RUNNING COSTS

In comparison with urban traffic, vehicles on rural roads maintain more even speeds. Firstly, the angle of deflection of horizontal curves per kilometre is smaller than that of urban street corners per kilometre. Secondly, at-grade intersections (in the case of non-freeways) are normally spaced a few kilometres from each other. As a rule, the more important road has the right of way at such intersections, which minimises speed changes and eliminates stopping on it. Thirdly, rural roads usually pass through non-built-up areas in fenced road reserves so that they are not subject to external disturbances.

Because vehicles maintain a more even travel speed on rural roads and the causes of speed changes are easier to identify than under urban traffic conditions, microscopic analysis of fuel consumption is easier on rural roads than on urban ones. By using speed as an independent variable to determine fuel consumption, a speed profile can be simulated by means of such variables as vehicle class, road geometry and traffic. In such analyses, fuel consumption rate at a constant speed on a flat straight road section is usually the point of departure. Changes in fuel consumption rates are usually attributed to the following: (1) changes in the rate of vehicle movement; (2) changes in the horizontal direction of movement; and (3) vehicle movement along upgrades and downgrades.

3. RESEARCH NEED

Microscopic traffic analysis requires a maximum amount of data on road geometric and traffic variables, such which would only be available during the final road design stage, hence the detailed planning of a rural road should be far advanced before microscopic analysis can be reliably applied. With a view to early planning during which possible alternative routes are investigated, road user costs may be less accurately estimated through utilising macroscopic analysis. During these early stages of rural road planning, roads may be classified according to type (paved divided carriageway, paved undivided carriageway and gravel) and topography (flat, rolling and mountainous). Sometimes the terrain is such that a relatively flat road may have a winding horizontal alignment, or a relatively straight road a rolling profile. The nature of such roads and their geometric features are identified in this article.

4. RESEARCH METHOD

To empirically (i.e. experimentally) estimate the fuel consumption rates of the vehicles that will make use of a road, it is necessary to divide the relevant vehicle population into representative classes and to select test vehicles for fuel consumption measurements that will reliably represent the fuel consumption of each class. During extensive fuel consumption measurements on rural roads in South Africa in 1990, the local vehicle was divided into the following six classes: (1) cars; (2) light petrol-driven vehicles other than cars; (3) light goods vehicles; (4) medium-sized goods vehicles; (5) heavy goods vehicles; and (6) buses. A statistically representative test vehicle within each class was selected for measurement purposes. The following vehicles were used within each of the six classes: (1) Toyota 1.8 LS; (2) Toyota Hi-Ace; (3) Mercedes-Benz Speedliner 811; (4) Nissan CW46; (5) Mercedes-Benz 0305; and (6) Mercedes-Benz 1926. Fuel consumption measurements on eight sections of divided paved roads, single-carriageway multilane roads and single-carriageway two-lane roads were conducted in different topographical terrain types in light, medium and heavy-density traffic conditions covering 360 kilometres per vehicle. Fuel consumption measurements on six gravel road sections in different topographical terrain types covering 66 kilometres per vehicle were conducted. All vehicles used in the measurements were 1990 models, and the results were subsequently published (Pienaar, 1993).

Technological advances are continuously making new road vehicle models more fuel efficient (Van Rensburg & Krygsman, 2015). From 1970 to 2012, the average fuel efficiency of all vehicle types in the USA increased at a rate of 0,9% per year (U.S. Energy Information Administration, 2015). On the assumption that this rate of fuel efficiency of all vehicles also holds for South Africa between 1990 and 2015, this means that the 1990 results described above for each vehicle class can be divided by 1,22 to approximate the fuel consumption rates of all vehicle classes in 2015. The opinion of 12 operational managers in the road freight and passenger transport industry, and academics who conduct research in transportation engineering and road economics concurred that the average fuel consumption (the inverse of fuel efficiency) of new road vehicles declined by between 20% and 25% from 1990 to 2015. In the light thereof it was judged that the results of the empirical fuel consumption results obtained with the 1990 model test vehicles should be divided by a factor of 1,22 to portray the average fuel consumption rates of South African vehicles in 2015.

5. TOPOGRAPHICAL TERRAIN CLASSES

The topography of the land through which roads run affects their vertical and horizontal alignment. To characterise variations, the American Association of State Highway and Transportation Officials separates topography for analysis purposes into three classifications according to terrain (AASHTO, 1984). These classes are flat, rolling and mountainous terrain. However, in some cases conditions may cause a road in flat terrain to have a winding horizontal alignment and a road in rolling terrain to have a straight horizontal alignment. In view of the significant prevalence of roads which are characterised by these geometric features, Pienaar (1993) proposed their inclusion as topographical categories for rural road planning and analysis, and defined the characteristics of the five classifications which are representative of South African conditions. These definitions have subsequently being used by the South African National Roads Agency (SANRAL) for rural road-planning purposes (Harmse, 2012).

The characteristics of the various topographical categories are as follows:

Flat terrain is the condition where road sight distance, as affected by horizontal and vertical constraints, is usually long and can be made long without any major construction or earthwork. Gradients are below 2% and the radius of horizontal curves usually exceeds 2 000 metres.

Winding road alignment with a flat profile is the condition where topographic or land use considerations cause the alignment to be along a winding escarpment, ridge, coastline, river or wetland without any significant gradients in the profile. Road gradients are below 2%, and the radii of horizontal curves are approximately 800 metres for one-third of the distance and more than 2 000 metres for the remaining two-thirds.

Rolling terrain is the condition where the natural gradients rise evenly above and drop evenly below the road gradient, and where occasional steep gradients present a measure of constraint with regard to road alignment and profile. Road gradients are approximately 3,5% for two-thirds of the distance, while the remaining one-third of the distance is taken up by sag and crest vertical curves, and the radii of horizontal curves are approximately 800 metres for one-third of the distance and more than 2 000 metres for the remaining two-thirds.

Rolling profile with a straight alignment is the condition where the topography is characterised by successive ridges alternated by dales or valleys, with the road crossing them transversely. Economic or land-use factors prevent the profile from being made flatter by means of curves in the horizontal alignment or by excavations and fillings. Road gradients are approximately 3,5% for two-thirds of the distance, while the remaining one-third is taken up by sag and crest vertical curves, and the radii of horizontal curves are approximately 800 metres for one-third of the distance and more than 2 000 metres for the remaining two-thirds.

Mountainous terrain is the condition where there are sudden longitudinal and lateral changes in the height of the terrain so that stepping and excavations along slopes are necessary to obtain an acceptable vertical profile and horizontal alignment. Road gradients are approximately 6% for two-thirds of the distance, while the remaining one-third is taken up by sag and crest vertical curves, and the radii of horizontal curves are approximately 400 metres for one-third of the distance and more than 2 000 metres for the remaining two-thirds.

These vertical profile and horizontal alignment conditions of road types according to topographical terrain are summarised in Table 1.

Representative features of the six vehicle classes relevant to the planning and cost–benefit analysis of rural roads are supplied in Table 2.

6. RESULTS OF THE STUDY

The results of the study, namely estimates of the fuel consumption rates (in mℓ/km) of representative vehicle classes of the South African vehicle population on different rural road types, which are intended for macroscopic planning and cost–benefit analysis, are presented in Table 3.

7. CONCLUSIONS

With a view to the analysis of rural road vehicle fuel consumption, the South African road vehicle population can be divided into the following six classes: cars, light petrol-driven vehicles other than cars, light goods vehicles, medium-sized goods vehicles, heavy goods vehicles and buses.

During the early stages of rural road planning, roads may be classified according to type (paved divided carriageway, paved undivided carriageway and gravel) and five topographic terrain types, namely flat terrain, winding horizontal road alignment with a flat profile, rolling terrain, rolling profile with a straight horizontal alignment, and mountainous terrain.

Table 1. Assumed incidence of gradients and curves in various terrain types for use in macroscopic rural road analyses

Topography	Vertical alignment (profile)	Horizontal alignment (curvature)
Flat	0% gradient for one-third of distance 1% gradient for one-third of distance 2% gradient for one-third of distance	No effect as a result of curves because radii > 2 000 metres
Flat with winding alignment	The same as for flat topography	800-metre radius curves for one-third of distance, and > 2 000-metre curves for remaining two-thirds
Straight with rolling profile	3,5% gradient for two-thirds of distance, remaining one-third taken up by sag and crest vertical curves	The same as for flat topography
Rolling	The same as with rolling profile	The same as for flat with winding alignment
Mountainous	6% gradient for two-thirds of distance, remaining one-third taken up by sag and crest vertical curves	400-metre radius curves for one-third of distance and > 2 000-metre curves for remaining two-thirds

Table 2. Description of representative vehicle classes

Vehicle class	*Propulsion*	*Average tare (ton)*	*Number of axles*	*Assumed operating mass* (ton)*
Cars – sedans and station wagons	Petrol	1,0	2	1,2
Light vehicles (LVs) – minibuses, small light trucks and panel vans with four wheels and vehicle length < 5 metres	Petrol	1,4	2	1,9
Light goods vehicles (LGVs) – trucks and midibuses with a single rear axle and vehicle length > 5 metres	Diesel	3,0	2	4,2
Medium-sized goods vehicles (MGVs) – rigid trucks with two rear axles	Diesel	10,7	3	18,7
Heavy goods vehicles (HGVs) – all combination vehicles	Diesel	14,1	5	28,0
Buses – single-deck buses > 8 metres	Diesel	9,0	2	11,6

*Note: *Average operating mass equals total vehicle mass, which includes vehicle tare mass plus actual load mass during vehicle operation*

Table 3. Estimated fuel consumption by road vehicles according to rural road type and topography (mℓ/km)

Rural road type	*Vehicle class*	*Topography*				
		Flat	*Straight with rolling alignment*	*Flat with winding alignment*	*Rolling*	*Mountainous*
Divided paved roads	Cars	91	84	83	78	83
	LVs	107	104	102	105	107
	LGVs	126	123	119	126	138
	MGVs	298	292	280	295	322
	HGVs	367	356	344	359	439
	Buses	323	313	306	316	330
Undivided paved roads	Cars	89	80	74	77	97
	LVs	105	100	91	98	111
	LGVs	123	118	108	123	146
	MGVs	279	256	238	254	343
	HGVs	321	305	280	344	561
	Buses	289	275	251	268	348
Gravel roads which are being maintained	Cars	80	77	80	83	93
	LVs	94	93	98	104	117
	LGVs	123	117	128	143	168
	MGVs	250	246	221	269	369
	HGVs	320	334	344	408	656
	Buses	256	248	223	263	361

During early planning, when possible alternative routes are investigated, road-user costs may be estimated macroscopically by making use of Table 3 in the paper.

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