COST-EFFECTIVE PROVISION OF LOW-VOLUME ROADS IN SOUTH AFRICA

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ABSTRACT
South Africa's provincial and municipal road authorities are responsible for the maintenance of an extensive low-volume gravel road network. Given the significant deterioration in the quality of this network, it is questionable whether authorities can and should accommodate the relative maintenance intensity of gravel roads within the resource constraints they face. The high incidence of gravel roads was largely driven by decentralized provision and relatively cheap construction costs compared to sealed alternatives, but consideration should extend to the resources that are required for the routine maintenance and periodic re-gravelling necessary to uphold their design life. Planning generally was not extended over the life-cycle of low-volume roads, so shocks have been encountered with respect to haulage distances for gravel, erosion of longitudinal road gradients, climate change, and increases in traffic volumes. We therefore estimate and stress test the whole-life economic asset cost of a gravel road under South African conditions, and compare these results against a variety of sealed alternatives to determine the points at which gravel is no longer the most cost-effective surface option for low-volume roads. Each alternative surface includes a specification, schedule of inputs, and standard maintenance programme. The stress tests focus on variations in input prices, the potential labour intensity of road works, the cost of labour, road user costs, and the sensitivity of maintenance schedules and costs to environmental factors.

KEYWORDS
South Africa; road surfacing policy; low-volume roads; gravel roads; sealed roads; life cycle cost analysis; deterministic; precipitation volume; road gradient; haulage distance; shadow price of labour; labour-intensive construction; road accident costs; vehicle operating costs.

INTRODUCTION
This paper presents a South African specific life cycle cost analysis (LCCA) of alternative unsealed and sealed surfaces for low-volume roads, defined here as carrying 75 to 220 vehicles per day, to promote their cost-effective provision by the 278 municipal and 9 provincial road authorities. The LCCA explores the trade-offs between the investment, maintenance, rehabilitation, and road user costs of gravel, sand seal, slurry seal, single chip seal, cape seal, and ultra-thin reinforced concrete pavement (UTRCP) roads. Stress tests are performed according to local variations in the proximity of natural resources to roads, the price inflation of inputs, climate, topography, the cost of labour, and road user costs to ensure this study is robust and has

country-wide application. The results support a policy to seal low-volume gravel roads at a rate possible within budget limitations.
Roughly 75 per cent, or 459 957 kilometres (km), of South Africa's proclaimed road network is gravel, with an additional 131 919 km of un-proclaimed gravel roads (1). Most of this unpaved road network is classified as Class 4 rural collectors, which provide a road user access function. The remainder consists of Class 3 Provincial Trunk and Main Roads, which provide a road user mobility function. These lower order classifications translate into low traffic volumes on the gravelled networks. For example, 93 per cent of gravel roads in the Western Cape carry less than 250 vehicles per day (2).

The ownership of the proclaimed gravel road network is almost evenly split between provincial and municipal road authorities. While there is limited data on the condition of municipal gravel roads, 67 per cent of the gravel roads under provincial management were in poor or very poor condition in 2013 (1). Also concerning to authorities is the rate at which the gravel road networks appear to be deteriorating, with only about 50 per cent of the sampled provincial gravel roads having been in a poor to very poor condition in 2009 (3). The South African National Roads Agency (SANRAL) estimated in 2016 that it would cost approximately R36 billion to re-gravel all unsealed provincial and municipal roads in poor to very poor condition, which is 132 per cent of the combined national, provincial, and municipal road budgets for the 2017/18 fiscal year (1,4).

Despite the apparent fiscal constraints, the poor and worsening condition of the network, and low traffic volumes, municipal and provincial road authorities cannot wholly abandon this gravel road network as they are constitutionally mandated to maintain roads if they provide citizens with the only feasible means to access basic education or healthcare facilities (5). Additional sections of the low-volume gravel road network also warrant maintenance attention due to their contribution to economic activity. Given that authorities must therefore accommodate at least a portion of the deteriorated low-volume gravel road network within their available budget envelopes, it is sensible to question prior to an extensive rehabilitation exercise whether gravel, as the current default option, is the most cost-effective surface for these roads given concerns about the sustainability of the replacement rate of gravel, the relatively high road user costs, and the relevance of a capital-intensive road surface in the context of consistently high levels of unemployment.

This paper applies a deterministic LCCA framework to answer this question. As advocated by Walls and Smith (6), the following procedural steps are taken in the subsequent sections of the paper to effectively conduct the LCCA: establish common and technically appropriate surface alternatives for the analysis period; determine performance periods, activity timing, and activity costs; estimate and stress test surface costs based on realistic scenarios; develop expenditure stream diagrams; compute NPV scenarios; analyse the results; and finally evaluate surfacing strategies.

THEORETICAL FRAMEWORK

LCCA is an analytical technique that uses initial and discounted future costs to evaluate the overall long-term economic efficiency of competing alternative investment options (6). In the context of this paper, LCCA compares the whole-life cost of alternative road surfaces to identify the lowest-cost option that satisfies the sought performance objective. This analysis helps inform investment decisions and has thus been endorsed by several organisations, including the United States Federal Highway Administration (FHA), and notably applied by Demos (7) for the Colorado Department of Transportation (DoT), Crovetti and Owusu-Ababio (8) for the Wisconsin DoT, Lamptey *et al*. (9) for the Indiana DoT, and Rangaraju *et al.* (10) for the South Carolina DoT.

To compare alternative road surfaces, LCCA uses an appropriate discount rate to convert all costs that occur throughout the life-cycle of each option to their Net Present Value (NPV). The benefits of providing and maintaining a standard pre-established road condition, along with uniform agency costs across surface alternatives - such as planning, design, and administration - are excluded from the LCCA as they are consistent across all surfaces (11). Road user costs, which include vehicle operating costs and accident costs, are addressed separately through stress tests, so the baseline model is focused on minimising road agency costs. The life-cycle costs under review thus include all differential planning, design, construction, periodic and routine maintenance, rehabilitation, and salvage costs associated with each surface option. The salvage cost includes the residual value and serviceable life of a pavement at the end of the analysis period, and is calculated based on the recyclable value of the pavement if it has reached the end of its serviceable life or the remaining life as a prorated share of the last major rehabilitation cost (12). The salvage cost, which is positive, is netted from the costs to arrive at the total cost of each alternative surface design.

The NPV is calculated as follows:

$$NPV = C + \sum_{i} M_i \,(1 + r)^{-x_i} - S(1 + r)^{-z}$$

where *NPV* is the present value of all costs, *C* is the present cost of the initial construction, M_i is the cost of the *i*th maintenance or rehabilitation measure, *r* is the real discount rate, x_i is the number of years from the present to the *i*th maintenance or rehabilitation measure, *z* is the analysis period, and *S* is the salvage value of road surface at the end of the analysis period.

Inputs for the various road surface cost variables can be generated via deterministic or probabilistic approaches. A probabilistic approach accounts for the risk of variation within the individual cost assumptions, projections, and estimates by using Monte Carlo Simulation to generate multiple outcome scenarios based on random samples from the cost inputs consistent with their defined empirical distributions (6). These outcome scenarios define an overall composite NPV probability distribution for each road surface, showing the full range of possible outcomes for each variable and the likelihood with which a particular outcome will occur. While the probabilistic approach is advocated due to the natural stochastic characteristics of factors affecting road performance, its application is reliant on large volumes of data which are unavailable for South Africa.

This paper therefore adopts a deterministic approach, in which fixed, discrete costs are applied for each of the road surface variables based on evidence or professional judgement of what value is most likely to occur (13). These fixed costs are collectively used to estimate the life-cycle cost for the design alternatives. Sensitivity analyses are then conducted on a selected set of the assumptions made for major cost variables to account for uncertainty of the outcomes. Although a deterministic approach precludes simultaneous variations in multiple inputs and simplifies the degree of uncertainty associated with life-cycle cost estimates, it is the appropriate choice in the context of data constraints and as such was applied in two-thirds of the transport specific LCCA studies reviewed by Ala-Risku (14).

SPECIFICATIONS AND COST DATA FOR LOW-VOLUME ROADS

This study is based on the Class 3 and Class 4 road sections from the Western Cape Government's Geometric Manual (15). Class 3 roads are the lowest class of sealed roads and are designed for annual average daily traffic (AADT) of 200 to 400 vehicles. This road class is comprised of two 3.4 metre (m) surfaced lanes, and two 0.9 m surfaced shoulders and 0.6 m roundings constructed to the same standard as the lanes. Class 4 roads have the same cross section except they are unsurfaced. The cost estimates presented in Table 1 reflect these cross-section profiles. While it is common for LCCA studies to altogether ignore the construction and maintenance works related to the verge given that many activities are common across the surface alternatives (10), this analysis accounts for the extra brush and weed control required for sealed roads to improve sight distance given higher vehicle speeds. Road markings on sealed roads are also considered.

The FHA (6) extends road design to include all pavement layers, which is appropriate for several reasons: the decision to seal a gravel road requires an upgrade of the pavement structure; these additional layers affect rehabilitation costs; and the severe deterioration of South Africa's gravel road network often necessitates rehabilitation activities. The TRH 4 Manual (16) specifies that roads carrying between 75 and 220 mostly light vehicles per day should have a design bearing capacity of 0.1 to 0.3 million equivalent standard axles (ES0.3) per lane. The untreated ES0.3 pavement cross-section is divided into 5 elements: subgrade (150mm of G10 gravel/soil); selected (150mm of G9 gravel/soil); subbase (125mm of G6 natural gravel); base (125mm of G4 crushed or natural gravel); and a wearing course or surface. Except for the base, which is not necessary for gravel roads, the pavement structure should be prepared in the same way for low-volume gravel and sealed roads if identical traffic volumes are assumed (17). This assumption does, however, ignore the fact that a sealed road may attract diverted traffic and induce additional investment. If the pavement structure is prepared in the same way, any use of naturally occurring soils and gravels (which are generally 25 per cent cheaper than crushed stone), compaction, or cement treatment are constant across the surface alternatives.

Table 1 captures the empirical data supplied by three experienced pavement engineers for the low-volume road surfaces considered in this study. The data was also cross-checked by representatives from SANRAL and the Southern African Bitumen Association (SABITA) to ensure its accuracy. Given the similarity in their characteristics and the results, sand seals are illustrative of slurry seals throughout this paper. The data is recorded per activity and disaggregated by the key inputs. The estimates presented in Table 1 assume that the road has a flat gradient, is in a moderate climate zone, and an average of 7 km from the closest borrow pit. In the absence of a geo-referenced registry of borrow pits, Ross and Field (18) assumed an average distance of 7 km between borrow pits based on reference to a Namibian study and consultations with three experienced South African pavement engineers. The applied maintenance strategies prioritise more frequent but less intensive maintenance interventions. This strategy responds to the nonlinear deterioration of roads by timeously addressing skid resistance and riding quality issues rather than waiting until the road condition is so impaired that it requires expensive rehabilitation actions (19).

While this empirical data shows that gravel roads are relatively more capital-intensive than the alternative surfaces, it also suggests that local contractors have not managed to optimise the labour-intensity of construction and maintenance works on sealed roads as touted by, amongst others, SADC (20). This signals that future data might weight the labour component for sealed roads more heavily, especially given government's attempts to promote community works programmes and small-scale contractor development. Projects using UTRCP have managed to absorb more than double the relative volume of unskilled workers as gravel roads.

TABLE 1 Pavement work schedules and costs, 2017 (Rands per km)

	Gravel	**Sand seal**	**14 mm cape seal + 1 slurry**	**14 mm + 7 mm double seal**	**UTRCP**
Serviceable life	8 years	20 years	20 years	20 years	30 years
Construction					
Total cost	R 3 000 000	R 3 500 000	R 4 000 000	R 4 250 000	R 6 500 000
Haulage	*R 150 000*	*R 374 500*	*R 376 000*	*R 374 000*	*R 344 500*
Unskilled labour	*R 180 000*	*R 280 000*	*R 360 000*	*R 340 000*	*R 780 000*
Bitumen	*NA*	*R 71 887*	*R 109 720*	*R 135 635*	*NA*
Routine maintenance: Minor repairs and clean-up operations, including grading and blading					
Frequency	4 per year	4 per year	4 per year	4 per year	4 per year
Total cost	R 100 000	R 100 000	R 100 000	R 100 000	R 50 000
Haulage	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
Unskilled labour	*R 50 000*	*R 50 000*	*R 50 000*	*R 50 000*	*R 25 000*
Bitumen	*NA*	*R 5 000*	*R 5 000*	*R 5 000*	*NA*
Periodic maintenance: Reseal of light seals					
Frequency (years)	NA	4;12;20;28	NA	NA	NA
Total cost	NA	R 350 000	NA	NA	NA
Haulage	*NA*	*R 6 300*	*NA*	*NA*	*NA*
Unskilled labour	*NA*	*R 28 000*	*NA*	*NA*	*NA*
Bitumen	*NA*	*R 134 133*	*NA*	*NA*	*NA*
Minor rehabilitation: Strengthening of the surface layer through re-gravelling, repair, and reseal					
Frequency	4 years	8 years	10 years	10 years	20 years
Total cost	R 300 000	R 850 000	R 1 100 000	R 1 150 000	R 1 500 000
Haulage	*R 28 200*	*R 34 850*	*R 37 400*	*R 37 950*	*R 19 500*
Unskilled labour	*R 18 000*	*R 68 000*	*R 99 000*	*R 92 000*	*R 225 000*
Bitumen	*NA*	*R 134 028*	*R 98 410*	*R 168 577*	*NA*
Major rehabilitation: Intensive re-gravelling and resealing to extend serviceable life					
Frequency	8 years	20 years	20 years	20 years	30 years
Total cost	R 800 000	R 1 550 000	R 1 800 000	R 1 825 000	R 4 100 000
Haulage	*R 84 800*	*R 91 450*	*R 93 600*	*R 94 900*	*R 57 400*
Unskilled labour	*R 48 000*	*R 124 000*	*R 162 000*	*R 146 000*	*R 492 000*
Bitumen	*NA*	*R 31 000*	*R 40 290*	*R 34 675*	*NA*

Source: Own calculations.

MAIN DETERMINANTS OF LOW-VOLUME ROAD COSTS

As traffic volumes on most of South Africa's rural roads are relatively stagnant at AADT less than 200, the agency life-cycle costs of low-volume roads are predominantly driven by environmental factors, resource availability, and resource costs. The first of these factors is climate, primarily temperature and moisture. Effects of extreme road surface temperatures, greater than 60°C or below 0°C, on pavement behaviour and performance include cracking, permanent deformation, warping, curling, evaporation, weathering, speed of reactions, ageing, and drying out of materials (19). Extreme moisture, scoring higher than 20 on Thornthwaite's Moisture Index, influences safety, drainage, erosion rates, permeability, material strength, and material selection (19). The implications for construction costs in wetter regions are generally a thicker pavement structure to improve the bearing capacity of the road, deeper side drains, and more sophisticated subsoil drains. High levels of precipitation also increase the frequency and cost of routine maintenance on gravel roads, and during large storms there may even be significant gravel loss. Similarly, road gradients greater than 6 per cent impact negatively on the rideability of gravel roads and require an increase in the frequency and cost of routine maintenance to retain the road's original design life.

The local price of bitumen increased with alarming volatility from the mid-2000s, driven largely by changes in the world cost of petroleum products and supply challenges caused by shutdowns at South African oil refineries. This price volatility has had a significant effect on road expenditure, as evidenced by the Gauteng Department of Public Transport, Roads and Works who in 2005 attributed the bulk of a 67 per cent year-on-year increase in the cost of sealing a low-volume gravel road to higher bitumen prices (18). Moreover, the supply shortages in 2013 meant that 15 per cent of local bitumen demand was covered through imports at a premium of R1500 per ton (21). Except for the price of fuel, which is similarly sensitive to world oil prices, the price of the remaining road surface materials have roughly tracked the building and construction sector price index (22).

Haulage, more through the marginal increase in fuel costs than through rental or depreciation of delivery vehicles, affects the life-cycle cost of low-volume roads. Maintenance of the local gravel road network requires approximately 30 million cubic metres of aggregate material per annum, which at an average distance of 7 km between borrow pits equates to about 30 million litres of fuel per year (18). Sealed roads also incur haulage, but the cost is marginal and infrequent following the construction phase. In fact, Ross and Field (18) and Jahren *et al.* (11) found that sealed roads accrued lower oil-based costs than gravel alternatives once the haulage distance exceeds 11 km. While this specific distance is sensitive to shifts in oil prices and the exchange-rate, what is evident is that any change in haulage distance is likely to have a greater proportional impact on the cost-effectiveness of gravel roads. Given the onerous environmental impact assessments (EIAs) required by the Mineral and Petroleum Resources Development Act (Act 28 of 2002) to open new quarry facilities and the associated delays in the approval of mining permits, the recent trend has been towards a more uneven spread of borrow pits and thus increased haulage distances (23).

The high unemployment rates across South Africa reflect an abundance of underutilised labour that government is trying to mobilise through the Expanded Public Works Programme (EPWP), which calls for the application of labour-intensive production methods wherever the accounting cost is no higher than alternative capital-intensive methods. Ross and Field (18) argue that this prescription ignores the possibility of building the national asset stock by investing in human capital. The training provided to EPWP workers on road projects improves the productivity of individual contracting firms. This skills development also translates into higher potential national productivity and should thus be subsidised by government. The cost of labour from government's perspective should therefore not reflect the accounting wage of R83 per day for an EPWP worker in 2017, which has been artificially inflated above the market-clearing rate by labour unions and minimum wage regulation, but the opportunity cost of a potential EPWP worker's time, measured as the cost to the economy in terms of foregone output from moving that person from their present occupation to employment on an EPWP project. When these shadow wages are considered, the relative capital- and labour-intensity of the road surface has a significant effect on the LCCA.

Finally, discounting is an influential element of the LCCA. Higher discount rates lead construction costs to dominate maintenance costs, and vice versa. Higher discount rates therefore favour gravel roads, which have relatively low construction costs but frequent and relatively high maintenance costs, over sealed alternatives. Fortunately estimates of the discount rate in South Africa are within a relatively narrow band. The National Treasury's working rate of 9 per cent and Kuo *et al.'s* (24) estimation of 11 per cent are roughly in line with the World Bank's and Asian Development Bank's recommendation of 10 to 12 per cent for developing economies (25). A standard discount rate of 10 per cent is thus assumed throughout this paper.

LCCA RESULTS

The analysis period, which is the time horizon over which the pavement designs are evaluated, was set at 30 years to cover the longest design life, to incorporate at least one major rehabilitation activity per surface, and to reflect long-term cost differences associated with the alternatives (6). The tests that follow individually stress relevant cost determinants, and then introduce road user costs to guide authorities on a cost-effective surfacing policy under variations in local conditions.

Figure 1 presents the life-cycle cost profile of the alternative road surfaces in constant 2017 prices. This scenario, which serves as the baseline for this study, indicates that gravel roads are the most cost-effective surface option under the simplified standard conditions: flat road, moderate climate, and an average distance of 7 km between borrow pits. While the recurrent re-gravelling lowers the opportunity cost between gravel and sealed roads over the analysis period, the initial cost savings in the construction of gravel roads is the dominant factor once discount rates have been considered.

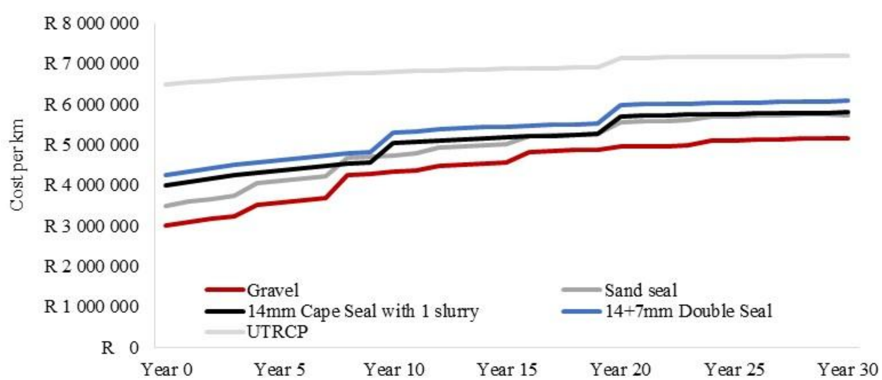

FIGURE 1 LCCA under standard conditions

The first stress test, which is not shown graphically as the results align with the baseline outcome in Figure 1, accounts for a scenario in which no significant bitumen supply is generated as a by-product of local fuel refining. While some additional bitumen storage capacity has been added following the supply crises in 2011 and 2013, the rationale for this scenario is the persistent risk of maintenance shutdowns at South African oil refineries and that growth in local oil refining volumes will not keep pace with growth in bitumen demand. To test the cost implications of this eventuality, price inflation was controlled for by applying an annual inflation rate of 4.4 per cent for the building and construction sector to all inputs except bitumen (22). This inflation rate was based on the annual average between 2011 and 2017, which excludes the price volatility introduced by the infrastructure drive in advance of the 2010 Soccer World Cup. The annual inflation rate of bitumen prices was set at 18 per cent, which captures the average between 2011 and 2014 when the recent supply shortages occurred. While gravel remains the cheapest surface option under these conditions, this marked increase in the price of bitumen did not cause a significant fluctuation in the life-cycle cost of sealed roads as bitumen is a relatively small component of the materials bills.

High moisture content and high precipitation volumes have a notable effect on the relative cost-effectiveness of gravel roads. A similar effect is evident for road gradients steeper than 6 per cent, hence the results shown in Figure 2 relate to both scenarios. Both phenomena generally necessitate two additional grading events per annum for gravel roads. High precipitation volumes also inflate the construction cost of sealed roads by 5 to 7 per cent to fund upgraded drainage and pavement strengthening. Despite the increased cost to construct a sealed road, in both scenarios the cost of the additional grading events erodes the initial construction savings on gravel roads by the eighth year. Authorities whose jurisdictions experience high volumes of precipitation or include hilly and mountainous areas should therefore consider adopting a policy of sealing gravel roads.

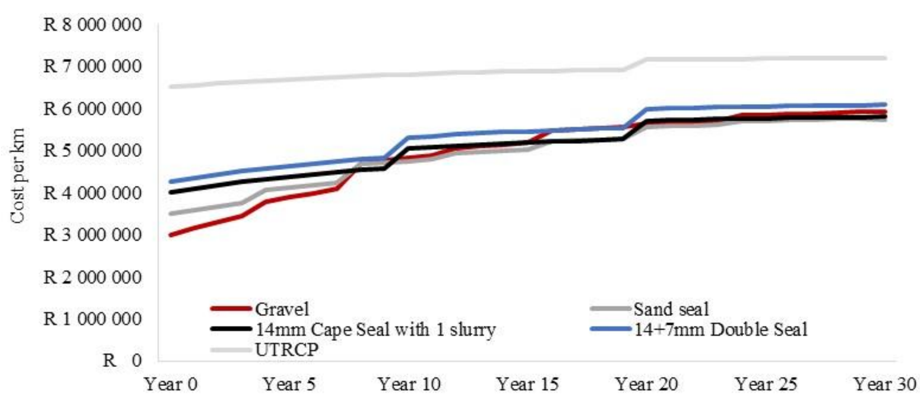

FIGURE 2 LCCA in areas with high precipitation volumes or steep road gradients

Haulage is a significant cost component of initial construction outlays for both gravel and sealed roads. While haulage falls away somewhat as a proportion of the rehabilitation costs for sealed roads, it remains a major cost driver throughout the life cycle of a gravelled road. Figure 3 shows that at the current diesel price of R10.84 per litre, a 15 km increase in the average distance between borrow pits would level the life-cycle costs of gravel and sand, slurry, and 14mm cape seal roads. It is therefore evident that sealed roads will become increasingly preferable should the EIA related pressures surrounding the opening of new borrow pits not subside.

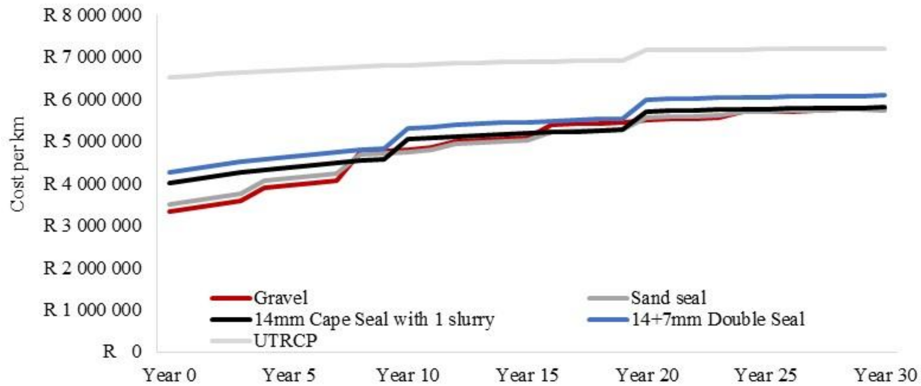

FIGURE 3 LCCA with a 15km increase in the average distance between borrow pits

The test in Figure 4 substitutes the EPWP wage for the shadow price of unskilled labour in South Africa. In light of the preliminary nature of estimates of the regional shadow price of labour, we here opt to set the shadow price of unskilled labour at 50 per cent of the EPWP wage for illustrative purposes. The fact that contractors have not maximised the labour-intensity of road works skews the analysis in favour of gravel roads, which in theory should be more capital-intensive than sealed alternatives and therefore a less attractive surfacing option given high unemployment rates and the low levels of informal sector productivity. The test therefore also artificially enhanced the labour-intensity of road works to demonstrate that a four-fold increase in the labour-intensity of works on sealed roads is required to roughly equalise the economic cost of providing gravel and sealed roads.

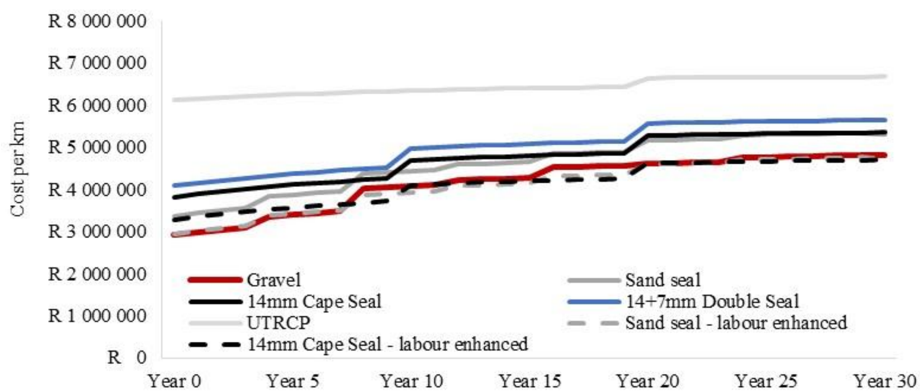

FIGURE 4 LCCA using the shadow price of labour and enhanced labour-intensity

Figure 5 incorporates the combined effects of road accidents and vehicle operating costs into the LCCA, assuming a traffic volume of 75 mostly light vehicles per day and a speed limit of 80 km/h. Working from World Bank (26) statistics on surface specific road accident rates in South Africa per 100 million vehicle-km, the 821 250 vehicle-km travelled per 1 km stretch of modelled road over the 30-year analysis period would lead to approximately 1.89 accidents on gravel roads and 0.82 accidents on surfaced alternatives. For the purposes of illustrating the full potential cost of road accidents, we here assume that the one additional accident on gravel roads is fatal and apportion the cost of this incident - valued by the Road Traffic Management Corporation in 2015 at R5.44 million (27) - over the analysis period. In addition, the roughness of gravel roads can increase vehicle operating costs through fuel and oil consumption, depreciation and interests, tyre wear, and maintenance and repairs. This test, however, is restricted to fuel consumption only as this tends to be the most significant and transparent vehicle operating cost. At an average fuel consumption of 9.89 km per litre (29), this equates to 2 768 litres of fuel per annum to cover the 27 375 vehicle-km. Studies have shown that average fuel consumption over different weather conditions and phases of the road maintenance cycle is approximately 8.8 per cent higher on gravel roads (28). At the current price of R10.84 per litre of diesel, an extra 8.8 per cent fuel consumption equates to R2 640 per annum. Despite this limited scope in vehicle operating costs, the results in Figure 5 still show a marked deterioration in the relative cost-effectiveness of gravel roads once the effects on road users are considered.

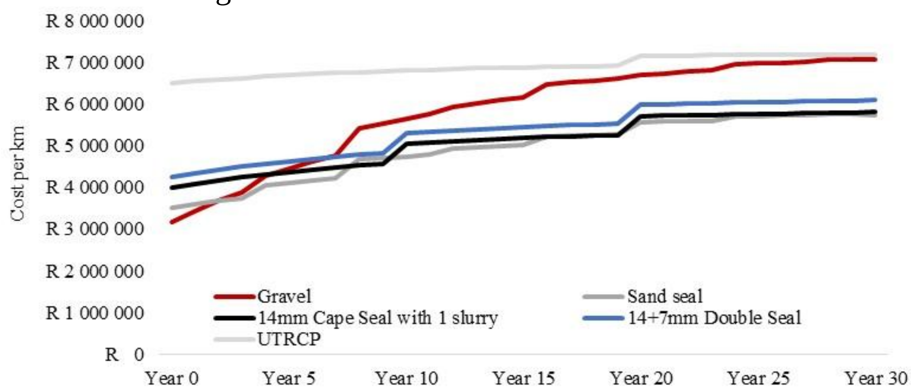

FIGURE 5 LCCA accounting for fuel consumption and road accident costs

CONCLUSION

Additional benefits of sealing gravel roads include: faster vehicle speeds resulting in shorter travel times; a potentially enhanced tax base stemming from increased prices of neighbouring properties; reduced dust emissions and a subsequent reduction in cases of eye and respiratory issues; and better vegetation and crop growth on adjacent land (11). These factors should improve the relative cost-effectiveness of sealed roads and therefore shorten the time period within which the upfront investment in sealing of gravel roads is recouped.

Our baseline condition represents an ideally simple world for surfacing decisions. A few regions of South Africa, like the Karoo, might approximate this world. However, such regions are sparsely populated and are not the sites of many factor-sensitive surfacing decisions. Policy should thus not be driven by the ideally simple case, but by reference to tendencies in the relationship between complicating factors and relative surface construction and maintenance costs. All factors examined here individually eliminate the cost advantage accruing to gravel in the ideally simple world.

There is near-unanimity among economists that South Africa's most urgent policy priority is improving the quality and extending the distribution of lower-skilled human capital that has a non-negative shadow value. Indeed, the policy priority to increase employment rates, community participation, and skills development through labour-intensive road projects is captured as part of the Provincial Roads Maintenance Grant (PRMG) outcomes (30). Such assessment should be done in terms of utility, not monetary value. However, there is no meaningful room for doubting that, in South Africa, if a policy A dominates or ties with a policy B in terms of expected monetary value, but A contributes more to the human capital stock amongst citizens with relatively low levels of formal education, than A dominates B with respect to optimizing public utility. Our analysis indicates that choosing sealed surfaces over gravel surfaces is an "A-type" policy where the overwhelming majority of real road surfacing decisions are concerned.

One of the requirements attached to the PRMG, which comprised 44.3 per cent of total provincial road expenditure in 2016/17 and as much as 77 per cent in the Northern Cape, is that the funds are allocated to rehabilitation or routine, periodic, and special maintenance (30). The requirements in fact stipulate that the PRMG cannot be used to upgrade gravel roads to surfaced roads, meaning that provinces have had to fund road upgrades from their equitable share or own revenues. While this restriction has had an obvious stifling effect on the surfacing policy adopted by provincial road authorities, a newly proposed version of the PRMG framework seeks to relax this condition and add 'number of kilometres of roads upgraded' as an outcome target measure. This amendment would provide necessary financial support to allow more rapid sealing of gravel roads.

The surfacing policy promoted by this paper is aligned with all the general conditions required for the sustainable provision of low-volume roads (20). Over-and-above the fact that the labour-intensive construction and maintenance works on sealed roads can be decentralised to small contractors and local communities, in line with government policy, the techniques associated with these works are technologically appropriate in the South African context. Moreover, internal human resource constraints have already led some road authorities – for example the KwaZulu-Natal DoT – to promote sealed surfaces to minimise the maintenance commitment of low-volume roads through their design life. Our findings thus give support to the proposition that, in South Africa under its current economic and institutional conditions, if a road is worth maintaining at all it is worth sealing.

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