

# MINIMISING TRANSPORT COSTS THROUGH OPTIMAL UPGRADING OF ROADS AND LOADING ZONES

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## Abstract

Infield to zone transportation with agricultural tractor-trailer units may incur costs of up to nine times those of long distance truck-tractor units. This necessitates the implementation of an optimal cane extraction road network. This paper describes formulas derived to evaluate whether the construction of additional roads and loading zones could enhance a farm's profitability. The formulas were subsequently applied in a case study typical of a 250 ha commercial sugarcane farm in South Africa, to quantify the technique's economic value and to demonstrate additional practical constraints. Transport savings were calculated at R23 000 per annum, and costs incurred on capital expansion was recovered after six crop cycles (ratoons). The results suggest that significant reductions in transport costs can be achieved in the South African sugar industry, especially by increasing the number of loading zones on existing roads. The case study did, however, identify several other factors, such as topography, cash flow requirements and vehicle utilisation issues that may alter road upgrading decisions. This work has been based on similar analyses currently under way in the South African timber industry.

*Keywords:* sugarcane, transport, loading zone, farm roads, cane extraction, harvesting, economics

## Introduction

In the South African sugar industry, transport costs make up 23% of total farm overheads (1personal communication). In a typical harvesting system, vehicles designed for infield transport, such as tractor-trailer combinations, transport cane from the field to easily accessible loading zones. Long distance truck-trailer vehicles then transport the cane from the loading zone to the mill. Because of this, farms will typically have a dense network of low cost tractor-trailer roads, also known as C-Class roads, and a considerably sparser road network for long distance trucks. Truck roads, known as B-Class roads, are built at high costs and often include hardened surfaces constructed of material from quarry sites.

Tractor-trailer transportation may incur costs of up to nine times that of truck transportation. This necessitates the implementation of an optimal cane extraction road network. The South African timber industry recently embarked on an assessment of road networks, including assessments of road network densities (Ackerman, 2001), loading site (depot) densities and the suitability of roads to enable trucks to penetrate deep into forested areas (Morkel, 1999; Lusso, 2004). Although there are many differences in the practices used in the sugar and timber industries, various generic approaches were followed when assessing the

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abovementioned timber transport issues.

The aim of this study was to mathematically derive and apply formulas that describe and optimise properties of on-farm cane extraction roads and loading zones. Specific objectives were to (i) derive a formula to assess loading zone density along a B-Class road, (ii) determine optimal routes for tractor-trailers to loading zones along B-Class roads and (iii) determine whether upgrading C-Class roads to B-Class roads would improve profitability. The abovementioned formulas were applied to a typical commercial sugarcane farm in South Africa to quantify economic values and to demonstrate additional practical constraints, such as topographic limitations.

## Methods

### *Model derivation*

#### Optimal spacing of loading zones on B-Class roads

Most farms have B-Class roads which are maintained for private activities. The density of loading zones on existing B-Class roads may significantly influence tractor-trailer costs. For example, if loading zones are situated far apart, then tractor-trailers will be required to travel long distances, which is not only expensive, but may also impact on harvest to crush delays. In contrast, more loading zones will reduce tractor-trailer transport, but will result in high road construction costs and cane production area will have to be sacrificed. The construction of a new loading zone should therefore only be undertaken if the costs incurred can be justified through reduced transport costs within a predetermined number of crop rotations (Equations 1 and 2).

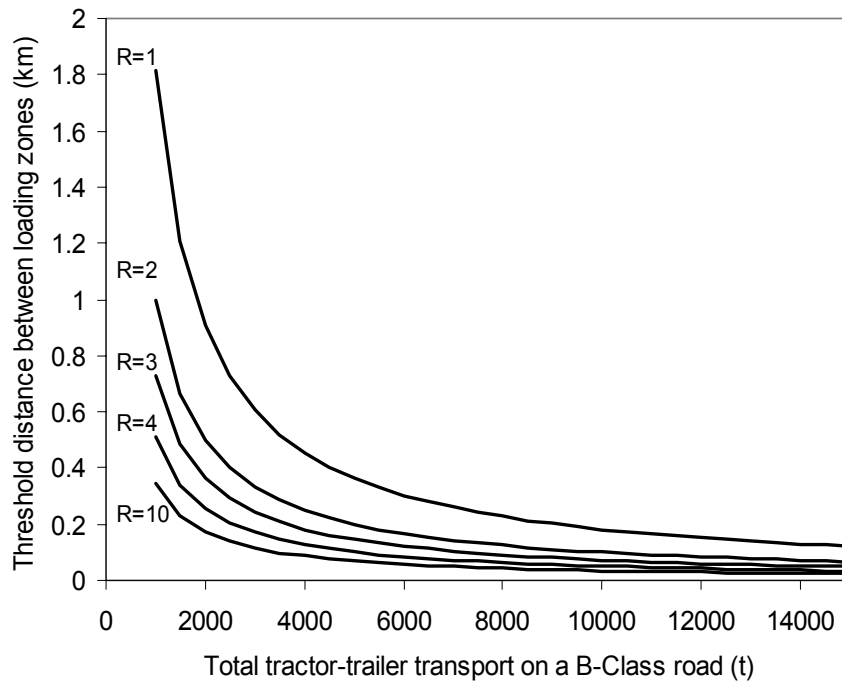
$$S \cdot d \cdot t \cdot R = z \left( \gamma + \frac{Y \cdot R}{10^4} \cdot P \right) + L \cdot d \cdot t \cdot R \quad (1)$$

$$\Rightarrow d = \frac{z}{t(S-L)} \left( \frac{\gamma}{R} + 10^{-4} Y \cdot P \right) \quad (2)$$

where

$S$	=	cost of tractor-trailer transport (R/t.km)
$d$	=	the tractor-trailer travel distance on a B-Class road (km)
$t$	=	tons cane transported in one rotation (t)
$R$	=	the number of rotations expected to pay for the upgrade
$z$	=	the size of a loading zone (m <sup>2</sup> )
$\gamma$	=	loading zone construction cost (R/m <sup>2</sup> )
$P$	=	the price of cane (R/t)
$L$	=	cost of long-distance haulage (R/t.km)
$Y$	=	long-term mean yield (t/ha)

From Equation 2 it can be seen that the break-even distance between two loading zones can be determined from the tons of cane transported by tractor-trailer on the B-Class road. Figure 1 illustrates this relationship for different values of  $R$ .



**Figure 1. Break-even distance between neighbouring loading zones against the on-road tractor-trailer transport. Different curves (*r*) reflect the number of crop rotations required to cover construction costs.**

#### Optimal delivery patterns between loading zones

If more than one loading zone exists on a B-class road, then, based on economics, cane should not necessarily be transported to the closest loading zone if that will result in cane movement against the direction of long distance vehicles. Figure 2 illustrates this concept and indicates that there exists a threshold distance ( $\delta$ ) that will economically justify tractor-trailers delivering cane against the direction of long distance vehicles. This threshold can be determined using the cost differential between tractor-trailer and truck-trailer transport (Equations 3 and 4).

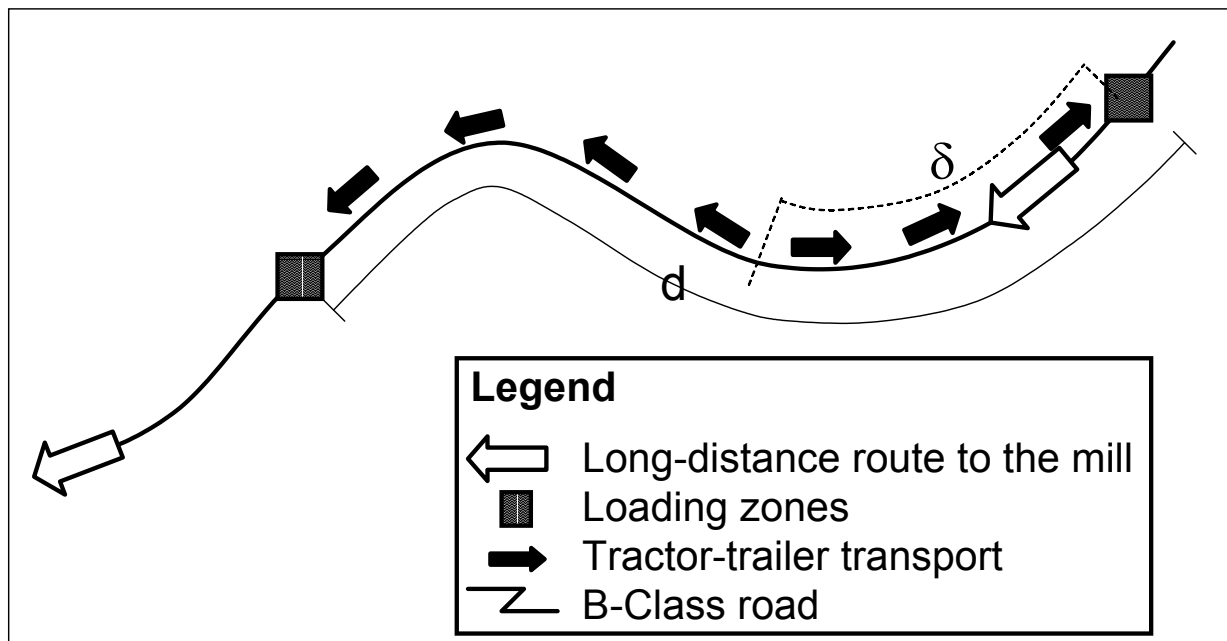
$$S(d - \delta) = S \cdot \delta + L \cdot d \quad (3)$$

$$\Rightarrow \frac{\delta}{d} = \frac{S - L}{2S} \quad (4)$$

where

$d$  = the distance between two loading zones (km)

$\delta$  = the maximum allowable distance for tractor-trailers to transport cane against the flow of long distance vehicles (km)



**Figure 2. Cane extraction routes for long distance vehicles (white arrows) and for tractor-trailers (black arrows). The distance  $\delta$  depicts the longest allowable distance for tractor-trailers to deliver cane against the flow direction of long distance vehicles.**

#### Upgrading C-Class roads to B-Class roads

It is strategically important to centralise loading zones so that large areas of cane can easily be transported to these zones. It may therefore be necessary to upgrade current C-Class roads in an attempt to reduce tractor-trailer transportation. However, the construction of a new B-Class road and an additional loading zone can only be justified if the construction costs and the losses due to reduced cane production areas are less than the cost of transporting cane by tractor-trailer to an existing loading zone (Equations 5 and 6).

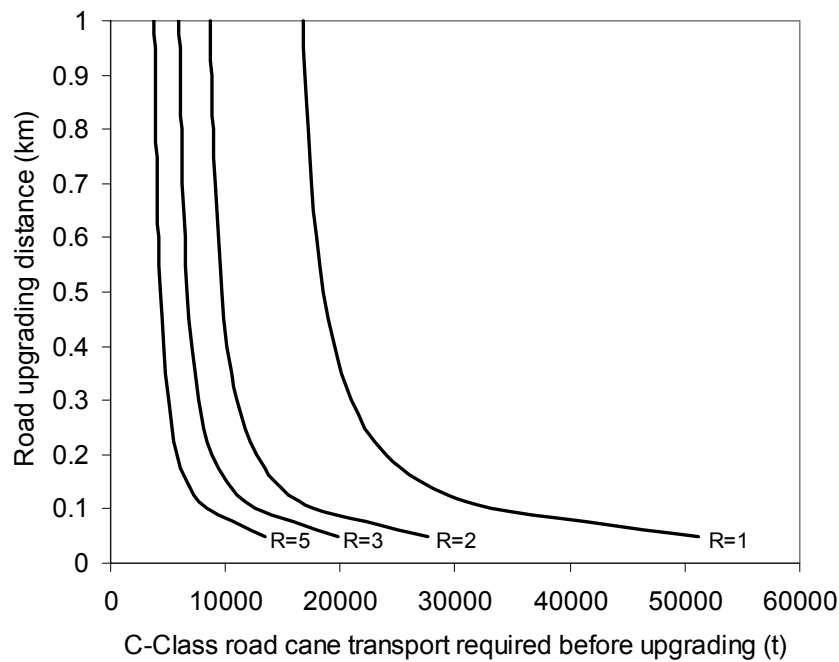
$$U \cdot D + \gamma \cdot z + L \cdot D \cdot R \cdot t + (z + 10^3 w \cdot D) \frac{Y \cdot P \cdot R}{10^4} = S \cdot D \cdot R \cdot t \quad (5)$$

$$\Rightarrow t = \frac{1}{S - L} \left[ \frac{z}{D} \left( \frac{\gamma}{R} + 10^{-4} YP \right) + \frac{U}{R} + 10^{-1} w \cdot Y \cdot P \right] \quad (6)$$

where

- $U$  = C-Class road upgrading costs (R/km)
- $D$  = the distance of the new C-Class road (km)
- $w$  = the difference in road width between B- and C-Class roads (m)

From Equation 6 it can be seen that a certain amount of cane tonnage needs to flow over a C-Class road to justify its upgrade to a B-Class road. This relationship is illustrated in Figure 3 under different cost recovery schedules ( $R=1, 2$ , etc).



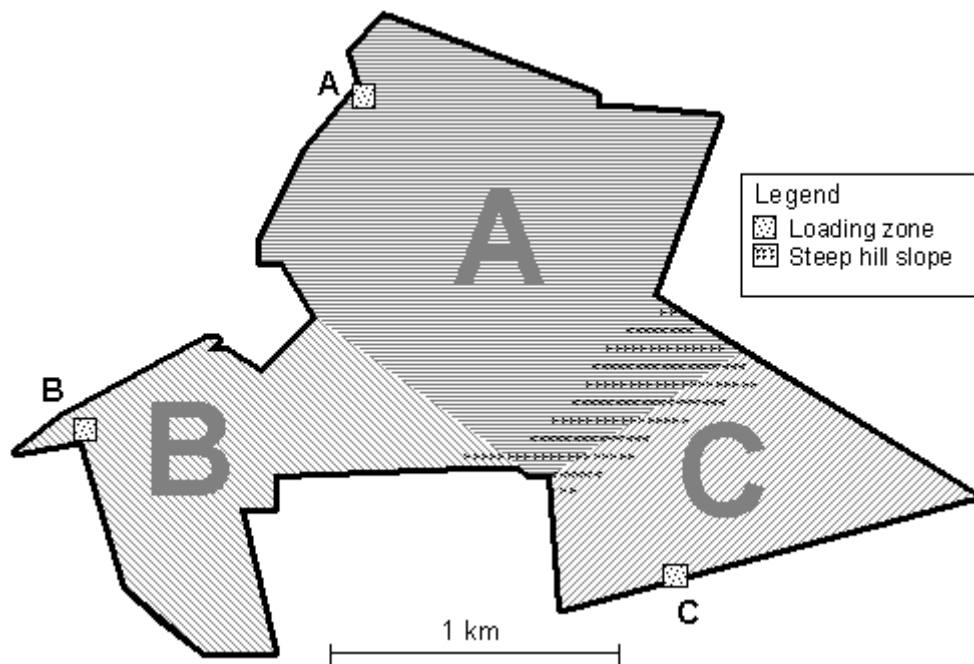
**Figure 3. Relationship between distance and threshold cane tonnage required to be transported on a road in order to warrant an upgrade to a B-class road.**

*A case study*

A typical commercial sugarcane farm in the Midlands South region was used to demonstrate the effects of the equations. The farm is 250 ha in size, with three loading zones situated on the boundaries (Figure 4). Table 1 summarises economic, crop size and road and zone dimension figures that were assumed. Costs were assumed to be recovered within five crop rotations, which, based a two year cutting cycle, equates to 10 years. The recovery period may vary significantly between growers, and a sound economic decision should be taken in this regard. Road upgrading costs were acquired from local consultants and coincided with figures in the timber industry. It was assumed that no road maintenance and no additional upgrading costs were required during the first 10 years after construction.

**Table 1. Economic (based on 2003/04 prices) and other variables assumed for this study.**

Variable	Description	Value
$S$	Cost of tractor-trailer haulage	R9.27/t.km
$R$	Number of rotations expected to recover costs	5
$z$	Size of loading zone	900 m <sup>2</sup>
$\gamma$	Loading zone construction cost	R15 m <sup>-2</sup>
$P$	Cane price at time of study	R168/t
$L$	Cost of long haulage	R1.00/t.km
$Y$	Long-term mean yield	100 t.ha <sup>-1</sup>
$U$	Road upgrading costs from C-Class to B-Class	R120 000/km
$w$	The difference in width between B- and C-Class roads	2 m



**Figure 4. Cane extraction profile on a typical commercial sugarcane farm in the Kwazulu-Natal Midlands. Three loading zones (a, b and c) are situated on the farm boundaries.**

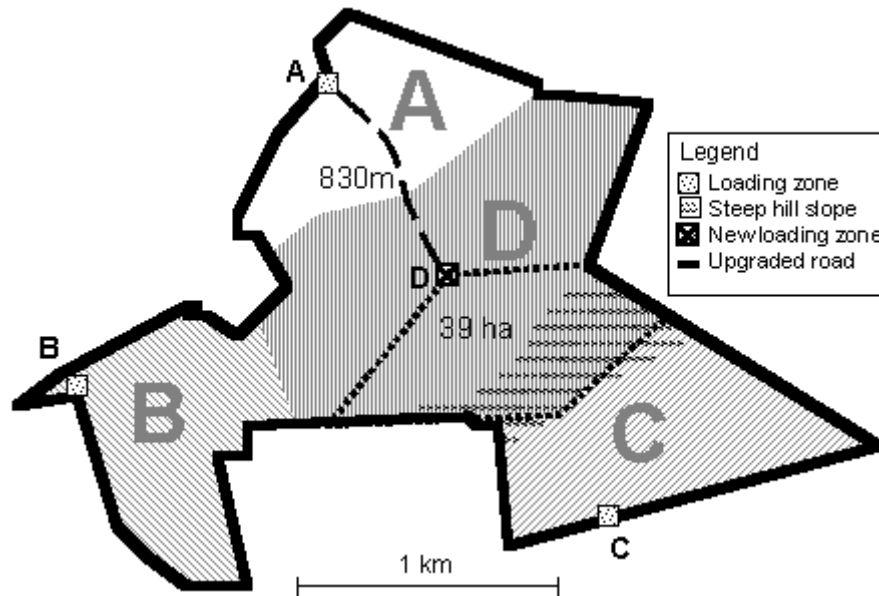
Cane has been extracted to the three existing loading zones according to Figure 4. A steep hill slope, unsuitable for long distance vehicles, divided cane delivery between Zones A and C. Geographically, Zone A was situated at a lower altitude and, due to the lower associated costs in transporting cane downhill, a large area of cane was extracted towards Zone A. Equations 6, 4 and 2 were subsequently applied to (i) motivate for an upgraded B-Class road into the extraction area of Zone A, (ii) redirect cane deliveries between different loading zones and (iii) determine whether additional zones on the upgraded road could be justified, respectively. In the case of constructing additional loading zones next to a B-Class road, loading zones were smaller than 900 m<sup>2</sup> (according to Table 1), since it was assumed that part of the road surface could be used for loading purposes ( $z=720$  m<sup>2</sup>).

The economic feasibility of the proposed changes was assessed using a capital budgeting technique according to Barry *et al.* (1995). The cost saving in transport was calculated assuming 40% taxation on profits and a 50, 30 and 20% depreciation of capital in years one to three, respectively. The change in net cash flow was calculated for each year and was expressed in present value terms, assuming a discount rate of 7%, constituted of 5% opportunity cost and 2% risk (2personal communication). Inflation was excluded, since all costs were calculated in real terms.

## Results

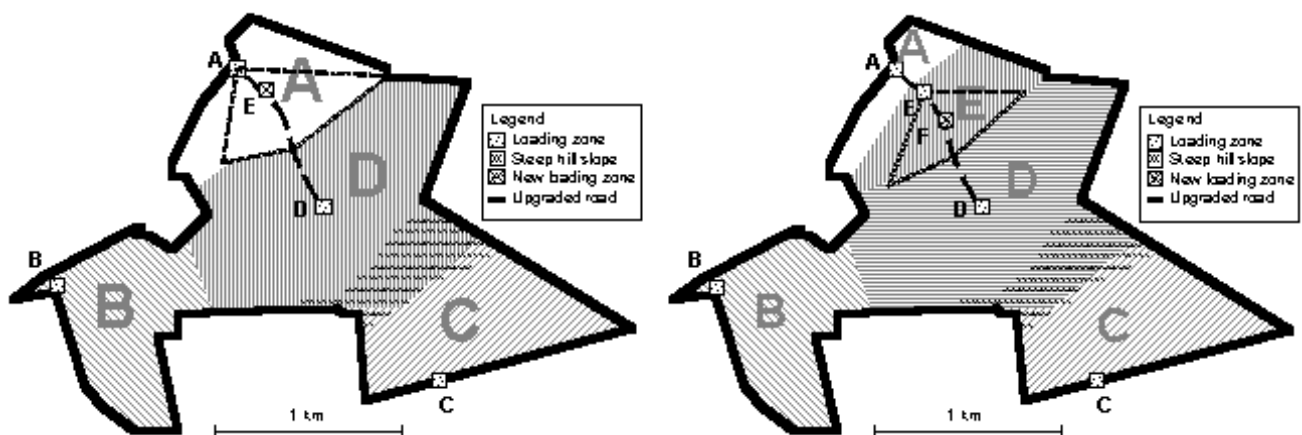
By applying Equation 6 iteratively, it was confirmed that 830 m of an existing C-Class road penetrating the cane extraction area in Zone A could be upgraded. Figure 5 illustrates the location of the road and new loading zone (Zone D). The threshold area (dotted line in Figure 5) of 39 ha was sufficient to justify the upgrade. It was calculated (using Equation 4) that the first 457 m (55%) of the upgraded road would be served by Zone A, due to the direction of long distance transportation. Figure 5 also illustrates the reallocation of cane areas to different

zones. It should be noted that large proportions of areas previously allocated to Zones A and B were redirected to Zone D. Zone D could therefore be expected to reduce costs more than anticipated in Equation 6, resulting in the recovery of costs over a period of less than 10 years.

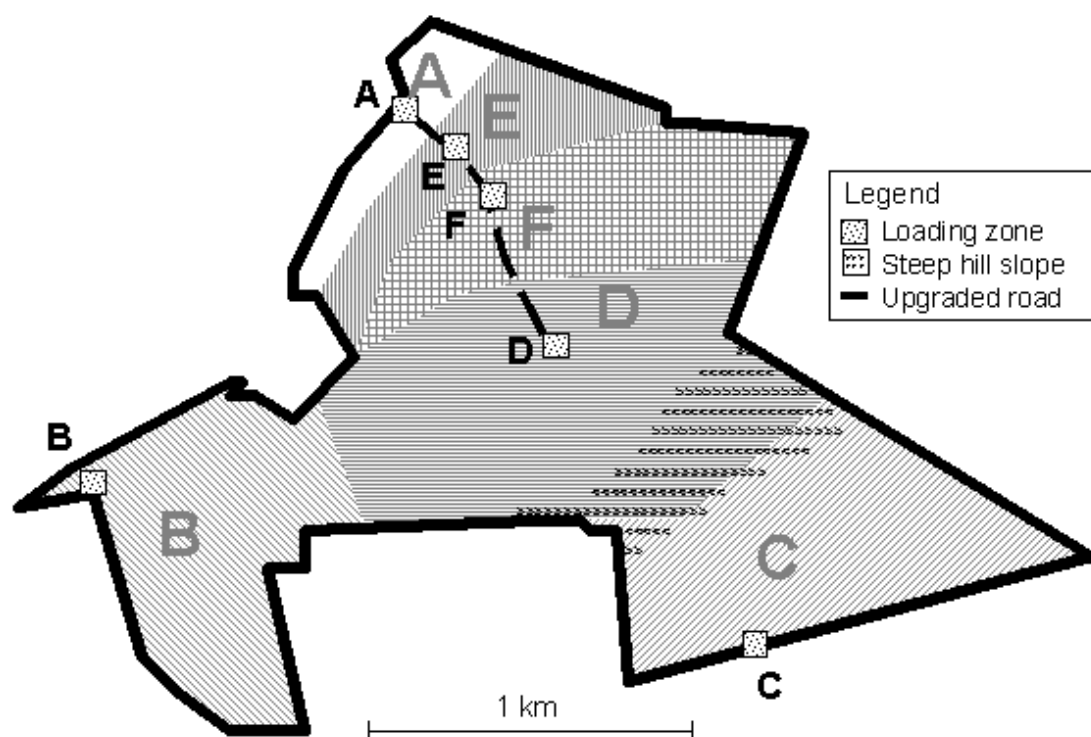


**Figure 5. Diagram of a new B-class road and loading zone constructed on a farm to reduce excessive tractor-trailer transport. The area indicated by the dotted line was sufficient to justify the upgrading of the 830 m C-class road.**

The new B-Class road running into the farm's interior created the opportunity to build additional loading zones along the road (using Equation 2). The proportion of Zone A's extraction area that would create tractor-trailer transport on the new B-Class road was identified (dotted line in Figure 6a). This area stretched from the loading zone to the end of the zone's extraction area at a 45° angle against the road and covered 35 ha. It justified construction of an additional loading zone (Zone E) 117 m from Zone A. The abovementioned procedure was repeated after the extraction areas were reassigned, and another loading zone (Zone F) could be justified 263 m away from Zone A (see Figure 6b). The remaining area did not justify the construction of an additional loading zone. Figure 7 illustrates the extraction areas served by each loading zone.



**Figure 6. Diagram showing how the construction of two new loading zones (zones e and f) was justified. Dotted lines indicate the cane areas where it was assumed that extraction by tractor-trailers would make use of the new B-class road.**



**Figure 7. Final road and loading zone network on a typical commercial South African sugarcane farm after a new B-Class road and additional loading zones were constructed.**

Table 2 gives a detailed capital budget summary on a year-to-year basis. The improved infrastructure resulted in transport expenditure savings of approximately R23 000 per annum. At the same time, loss in production due to a reduction in area under cane equated to R6 619 per annum. The economic break-even point was reached in the 12th year after upgrading. This contradicts the 10-year break-even approach that was assumed in Table 1 ( $R=5$ ). The main reason for this is because the formulas derived in this paper did not account for taxation, capital depreciation and the present value of future savings. This emphasises the importance of conducting a detailed economic analysis before making a decision to upgrade.

**Table 2. Capital budget summary of important economic issues that were considered in upgrading the road and loading zone infrastructure on a typical commercial South African sugarcane farm. All values are expressed in Rands.**

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
Road upgrade	(99600)												
Construction of Zone D	(13500)												
Construction of Zone E	(10800)												
Construction of Zone F	(10800)												
<b>Total Investment cost</b>	<b>(134700)</b>												
Cost saving in transport	22945	22945	22945	22945	22945	22945	22945	22945	22945	22945	22945	22945	22945
Losses in cane production	(6619)	(6619)	(6619)	(6619)	(6619)	(6619)	(6619)	(6619)	(6619)	(6619)	(6619)	(6619)	(6619)
<b>Net cost saving</b>	<b>16326</b>	<b>16326</b>	<b>16326</b>	<b>16326</b>	<b>16326</b>	<b>16326</b>	<b>16326</b>	<b>16326</b>	<b>16326</b>	<b>16326</b>	<b>16326</b>	<b>16326</b>	<b>16326</b>
Depreciation of capital		(67350)	(40410)	(26940)									
Change in taxable income	16326	(51024)	(24084)	(10614)	16326	16326	16326	16326	16326	16326	16326	16326	16326
Change in taxation (40%)	6530	(20410)	(9634)	(4246)	6530	6530	6530	6530	6530	6530	6530	6530	6530
<b>Change in net cash flow</b>	<b>(124904)</b>	<b>36736</b>	<b>25960</b>	<b>20572</b>	<b>9796</b>	<b>9796</b>	<b>9796</b>	<b>9796</b>	<b>9796</b>	<b>9796</b>	<b>9796</b>	<b>9796</b>	<b>9796</b>
<b>Present value of net cash flow</b>	<b>(124904)</b>	<b>34332</b>	<b>22674</b>	<b>16793</b>	<b>7473</b>	<b>6984</b>	<b>6527</b>	<b>6100</b>	<b>5701</b>	<b>5328</b>	<b>4980</b>	<b>4654</b>	<b>4349</b>
Net cash flow accumulated towards break-even	(124904)	(90572)	(67898)	(51105)	(43632)	(36648)	(30121)	(24021)	(18320)	(12992)	(8012)	(3358)	991

## Discussion and conclusions

The upgrading of a C-Class to a B-Class road or the construction of a new loading zone on, or next to, a B-Class road is directly related to the cane tonnage transported on that particular segment of road. Using the equations derived in this paper, it is easy to spatially assess a farm and determine whether a road upgrade and construction of additional loading zones would be justified.

This case study showed a significant improvement in transport expenses. The construction of new loading zones along existing roads appeared to be a particularly profitable exercise. In the light of previous recommendations that loading zones should be approximately one kilometre apart (Meyer, 1998), this suggests that many farms in the South African sugar industry may be managing harvest transportation at sub-optimal levels.

The formulas did not, however, account for the many peculiarities in cane extraction systems and farm economics. Topography and inaccessible land, for example, need to be assessed before applying these formulas. Likewise, there may be other economic issues, such as vehicle utilisation and cash flow requirements, that were not considered during the derivation of the formulas. For example, growers may consider implementing phases of road construction over several years, or decide to construct roads during the off-season when vehicle and labour utilisation is low. These actions, like many others, may alleviate cash flow problems and should be considered separately before any decision is made.

## Acknowledgements

The authors would like to thank the National Department of Transport for funding most of this project under a capacity building scheme. Mr Andrew McEwen and Mr Andy Immelman from Mondi and Sappi, respectively, supplied valuable advice and data that were used to derive and test the models. Dr Stuart Ferrer from the Agricultural Economics Department of the University of KwaZulu-Natal, Pietermaritzburg, is thanked for the guidance given with the economic analysis. Mr Francois Oberholzer of Forest Engineering South Africa, Pietermaritzburg, facilitated and co-ordinated several meetings between different role players.

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