DEVELOPMENT OF A SPATIAL SUGARCANE TRANSPORT INFRASTRUCTURE-PLANNING MODEL

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ABSTRACT

Due to the significant cost of transport in the sugar industry, a model, named FastTrack, was developed to investigate infrastructure planning opportunities. The model mathematically incorporates road construction and maintenance costs, terrain and land-use maps, vehicle performance specifications and annual sugarcane volumes to determine the most cost effective route, per vehicle type, from a production region to a mill. Route planning using geographical information systems (GIS) is a standard approach for determining the optimum alignment for pipelines, roads and canals. Theory of this approach was reviewed to create a foundation for the development of FastTrack.

A small portion of the Noodsberg sugar mill region in the KwaZulu-Natal midlands was selected as a case study area to test the capabilities of FastTrack. A start location was identified as a natural flow point for 70 000 tons of sugarcane hauled from an area south of the mill. Currently this volume is transported along a 9.3 km stretch of national road from the start location to the sugar mill, while the Euclidean distance is approximately 7 km.

Three vehicle types, differing in payload, fuel consumption and road speed were assessed. Two common and currently utilised vehicles, the tractor hilo and interlink combinations, were aligned by FastTrack along existing national roads. A financial penalty for driving on national roads was assumed for the third vehicle type considered, land trains, as these are currently not permitted to operate on national roads in South Africa. This high bulk vehicle was selected to test the capabilities of FastTrack and to identify if cost savings could be realised through increased consignment capacity as has been achieved in Australia, Malawi and Brazil. Utilising the model a new and more direct theoretical route was generated for the land train with a length of 7.4 km. Existing farm roads which would require upgrading made up 34 % of this proposed route. An economic analysis was conducted and showed that under current conditions, the private route generated by FastTrack for land train use, would be the most cost effective, with a system cost of R 57.50 t^{-1}. The tractor hilo and interlink had system costs of R 59.58 t^{-1} and R 60.98 t^{-1} respectively. Repeating the economic analysis with projected fuel prices indentified that the cost saving advantage of the land train system over the other two vehicle configurations increases with increasing fuel costs.

A rigorous validation process, including a sensitivity analysis of results from FastTrack, revealed that the model performs predictably under a wide range of input conditions and could be a valuable tool for decision making in the sugar industry. However, further research is required to combine more economic and logistical aspects into FastTrack and to increase its usability.

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1 INTRODUCTION

The South African sugar industry is one of the most important agricultural sectors in the country with an annual turnover of R 5 – 6 billion derived from a crop of approximately 21 million tons (Anon, 2008). South Africa is currently ranked as the eighth largest sugar exporter in the world market (Macleod, 2007) with approximately 80 % of the industry being located in the province of KwaZulu-Natal, and the remainder situated in the Mpumalanga province. The industry provides an estimated 350 000 jobs, which support roughly one million dependants (Anon, 2008).

Fuel prices have over the past four years risen significantly faster than the growth in the recoverable value (RV) price paid to farmers for delivered sugarcane. In the 2004 / 2005 season one ton of RV could purchase approximately 342 litres of diesel, whereas, in the 2007/2008 season, less than half this amount (169 litres) could be purchased. A study carried out by Pearce (2008) showed that, as a result the disproportionate escalation of transport costs compared to the price per ton RV, the break even crop yield for a 50 km farm to mill haul in the KwaZulu-Natal midlands has increased from 74 $t.ha^{-1}$ to 84 $t.ha^{-1}$ over the four year period from the 2004/2005 season to the 2007/2008 season. This is a significant increase and excludes depreciation, interest and management costs, which have also increased. According to Pearce (2008), current conditions will force farmers who have suitable soils and prevailing climatic conditions to consider replacing land under sugarcane with more profitable crops. This could have a significant effect on sugarcane supply to the mills.

Despite the increase in haulage costs and increasing road congestion, road freight accounts for more than 70 % of the total annual cost of all haulage logistics in South Africa (Braun, 2008). The development of improved infrastructure planning methods to create specialised and efficient freight routes is one of many areas where haulage costs can be reduced. There is possibly greater scope for infrastructure planning pertaining to specialised freight routes in localised areas, around central agricultural milling operations and storage facilities, such as in the sugar industry, compared to long-haul routes where land use and terrain can vary significantly. Other areas where haulage costs could be reduced include the pooling of farm resources, centralised logistics coordination and improved risk management strategies.

Traditional infrastructure planning methods consisted of assessing data from various sources in hard copy. Due to the amount of time required to prepare a precise result in this manner, only a few alternatives were ever considered for comparative purposes. GIS is described by Sadek *et al.* (1999) as a tool for overlaying layers of information, spatial or other, and for the display and analysis in a digital format. Information about any point on the digital surface can, therefore, be extracted or manipulated depending on the desired outcome (Lee and Stucky, 1998). GIS is consequently a tool used by modern infrastructure planners to enable a quick evaluation and selection of the most advantageous route between any two desired source and destination points (Saha *et al.*, 2005). GIS has been used to locate the optimum alignment of pipelines (Feldman *et al.*, 1995; Luettinger and Clark, 2005), forest road networks (Musa and Mohamed, 2002), and even a link road through the Himalayas based on minimising maintenance costs by effectively avoiding landslide risk areas (Saha *et al.*, 2005). Various route planning algorithms such as that presented by Yu *et al.* (2003) and Rees (2004), which are often based on graph theory developed by Dijkstra (1959), can be applied to layered information surfaces created in a GIS environment. These algorithms can be used to consider every possible path between any two or more selected points, indicating an optimal route based on predefined design criteria (Luettinger and Clark, 2005).

The aim of the research was to develop a spatial model which could be used to identify the most cost effective haulage routes for sugarcane transportation from field loading zones to the nearest mill. The model developed, named FastTrack, was required to consider not only existing roads but also the construction and maintenance of new, alternative, vehicle-specific, route alignments. Specific objectives of the research include:

- synthesising relevant literature to ensure that current knowledge is utilised in the development of an appropriate modelling solution,
- model development and validation, and
- practical implementation of the model in a case study.

2 THEORY AND PROCEDURES FOR ROUTE PLANNING IN GEOGRAPHICAL INFORMATION SYSTEMS

Route planning is the determination of a path alignment between any two or more points in space based on the optimisation of specific design criteria. Route planning exists because a straight line traced between two points is not consistently the most efficient path within a given set of design objectives. It can be conducted on existing infrastructure, such as identifying the fastest or shortest route between points with various limitations, and constraints being assigned to each of several available routes. It can also be used to locate the optimal position for new infrastructure, such as highways or pipelines. The latter type of route planning is the focus of this chapter.

2.1 GIS Route Planning Applications and Theory

2.1.1 Routing examples

Work carried out by engineers, scientists and computer programmers using GIS as a tool for route planning is considered in this section. The examples have been selected to demonstrate the wide variety of applications. Sections 2.1.2 - 2.1.4 contain more detail of the methodologies behind several of the presented models. The studies discussed below do not exhaust the literature, but rather provide suitable examples for this studies' specific context.

Feldman *et al.* (1995) developed an ARC / INFO - GIS model and tested it on a proposed section of an oil pipeline in the proximity of the Caspian Sea. The model was used to run a least-cost path analysis for the chosen section of pipeline and included base data, such as pipeline length, river, road and rail crossings, wetland zones, land-use, geology and topography. The determined solution, using the model, was a 51 km long pipeline as opposed to the straight line distance of 42 km, but the cost of construction was 14 % lower due to the reduced number of support structures required as a result of avoiding large topographic features and unnecessary crossings. This cost saving is the key advantage of almost all least-cost route planning applications in GIS.

Musa and Mohamed (2002) demonstrated the superiority of GIS route planning over traditional methods after comparing a hypothetical road network produced in both GIS and on paper to an actual route cut out by a civil contractor in a case study area. The results show that GIS route planning, in general, is both more time and cost effective than traditional methods, an argument also supported by Huang *et al.* (2004). The exception to this occurs when limited digitised data are available for a particular area, such as in a study by Sadek *et al.* (1999) where the project had to be extended by one year to collate the required data. The major cost-saving advantage of GIS route planning is realised in the ability of the algorithm to avoid "the most costly anomalies", such as existing infrastructure, steep slopes, river crossings etc. (Feldman *et al.*, 1995; Musa and Mohamed, 2002).

Lee and Stucky (1998) evaluated least-cost path (LCP) methods in a military application by introducing viewshed, or line-of-sight information into a GIS route planning model. The model was used to consider four differing sets of route criteria, based on inter-visibility factors, slope and distance derived from Digital Elevation Models (DEM), all aimed at concealing troops or enabling increased travel speeds. Varying weights were applied and a rasterised or grided friction surface was created for each criterion. Source and destination zones were later indicated enabling the model to create an accumulated friction surface from a specified source point. The model subsequently made use of an iterative searching procedure based on work by Douglas (1994) and indicated the path of least resistance or least cost depending on the various viewshed criteria for each of the four scenarios. The potential of this model for military use is evident, however, slight modifications could also extend its usefulness to town planning applications.

Collischonn and Pilar (2000) also formulated an algorithm developed for a rasterised GIS surface. The algorithm was of the least-cost path type and incorporated constraints, such as topography, slope, distance and construction costs. The authors applied the algorithm to two hypothetical cases *viz.* the construction of a road up a conical hill and a canal traversing undulating ground. Despite not using real values, the results were remarkably coherent with results anticipated from traditional route planning techniques (Husdal, 1999). The difference between this and other least-cost route planning algorithms available at the time is that the route plotted not only traces the least-cost path, but includes both the degree and direction of slope of an obstacle. This provides the potential for modelling certain circumstances where it may be more cost-effective to circumvent a slope rather than to proceed directly upward or downward (Husdal, 1999; Collischonn and Pilar, 2000). The concept of direction dependent movement proved an essential aspect for subsequent least-cost path algorithms (Yu *et al.*, 2003; Saha *et al.*, 2005).

Similar to work by Berg and Kreveld (1997) on pathways in the Alps based on vector surfaces, Rees (2004) analysed footpaths in Wales in the United Kingdom with raster GIS. Topography was initially considered as the only cost function, but potential new pathways were later considered based on both time of travel and metabolic effect imposed by the terrain on human locomotion. This was a relatively simple study but built on existing knowledge and further widened the scope of application for GIS route planning.

Saha *et al.* (2005) proposed a route planning model in the Himalayan mountains, building on many of the techniques proposed by the above-cited authors. Of particular note are the advances made by Yu *et al.* (2003), such as the bridge and tunnel function, and improvements in distance calculations which are discussed in Section 2.1.3. The model's major objective was to incorporate various thematic layers in an attempt to avoid landslide hazard zones, thus improving road safety and reducing future maintenance costs.

New algorithms for plotting and evaluating a route in GIS are continually being formulated and manipulated. None have, however, been as successful in their objective in determining a least-cost path than the one presented by Dijkstra (1959), which forms the starting point for many new route planning algorithms and is discussed further in Section 2.2.2.

2.1.2 Least-cost theory

Locating a path of least cost is, in most cases the intention when planning a new route. The cost can be expressed, as has been described in the examples in Section 2.1.1, in non-monetary terms. Included in this section is a description of the basic methodology followed by least-cost route planners and an explanation of Dijkstra's (1959) Algorithm, which is used as the starting point for many route planning applications.

2.1.2.1 Least-cost methodology

In GIS, the working surface, on which paths are plotted, can be considered as a grid made up of cells, containing information or evaluation criteria added in a GIS interface in layers. The following set of steps are necessary to create a least cost path, *viz.*

- Each layer of information is converted into a "friction surface" that relates to the cost of passage across any one of many cells constituting each surface (Douglas, 1994; Collischonn and Pilar, 2000; Atkinson *et al.*, 2005). In addition, each surface is required to be ranked in relation to the other remaining surfaces in a manner specific to a particular project (Lee and Stucky, 1998). As an example, the Caspian Sea was given a very high cost of passage, as a penalty, in a least-cost pipeline routing exercise carried out by Feldman *et al.* (1995), so that any route generated by the model would be forced to avoid it in an attempt to find the least-cost path.
- The layers of friction surfaces are then combined to create a "total friction surface", which represents the total cost of passage across each cell (Lee and Stucky, 1998; Atkinson *et al.*, 2005).
- A "spreading function" is then utilised, which calculates the total cost of passage from one or many initialising points, travelling onward to one or many destination points (Douglas, 1994; Lee and Stucky, 1998; Atkinson *et al.*, 2005). Dijkstra's Algorithm is often used for this as it allows for the selection of the path of minimum resistance (Rees, 2004). Fundamental to any spreading function is the manner in which the distance between any two cells is calculated. Yu *et al.* (2003) made significant improvements in this operation by considering variations in surface elevation. This is elaborated on in Section 2.1.3.
- Finally, the path of least resistance is traced across the accumulated cost surface resulting in the desired least-cost route from the start cell/s to the desired target cell/s (Lee and Stucky, 1998; Anderson and Nelson, 2004). An alternative to this is the generation of a "back-link" path, which allocates a number to each cell indicating the direction of least resistance between any start and destination points on the accumulated cost surface, thus mapping the least cost path in reverse (Xu and Lathrop, 1995; Lee and Stucky, 1998).

The least-cost methodology provides the basic structure for all route planning applications in GIS. Each step, however, is continually being refined in an effort to improve accuracy and computational speed.

2.1.2.2 Dijkstra's algorithm

Dijkstra's Algorithm (Dijkstra, 1959) has been widely utilised as a least-cost path function and, although modifications have been made to improve computational speed, such as by Solka *et al.* (1995) who introduced a parallel Dijkstra's Algorithm, the fundamentals remain intrinsically intact (Rees, 2004; Saha *et al.*, 2005).

Dijkstra (1959) posed two problems relating to identifying the shortest path between two nodes and across a network of nodes on a graph. In raster GIS, these nodes are the centres of the image or data grid cells, while the links between the nodes are represented by the connections between cells (Xu and Lathrop, 1994, 1995). Instead of describing Dijkstra's Algorithm as applied to graph theory, Rees (2004) listed the following six steps related to applying Dijkstra's Algorithm in GIS.

i. A cost of zero is applied to the target cell. The target cell is the destination or end point of the anticipated least-cost linear path.

ii. All the cells neighbouring the target cell are identified and placed in the list of 'active' cells. For each of these cells, the cost of reaching the target cell is calculated and assigned a pointer that points to the target cell.

iii. The cell in the list that has the lowest cost is identified and is called cell *C* with a cost *k* associated with it.

iv. The set *S* of all the neighbouring cells of *C* is identified. For each cell *C'* in *S*, the cost *l* of moving to *C* is calculated.
    - If *C'* is not yet a member of the list, it is then added to it with a cost $k + l$ and a pointer that points to *C*.
    - If *C'* is already a member of the list, then the value of $k + l$ and the provisional cost of this cell are compared. If $k + l$ is greater than or equal to the provisional cost, then no action is to be taken. However, if $k + l$ is less than the provisional cost, the attributes of the cell *C'* need to be adjusted so that its cost becomes $k + l$ and its pointer points to the cell *C*. This procedure is termed 'relaxation'.

v. The attributes of the cell *C* are then changed from provisional to definite, and removed from the list.
vi. The procedure restarts at (iii) and repeats until the list is empty.

Rees (2004) claims that the benefit of the above-applied version of Dijkstra's Algorithm is valuable in the sense that it computes the least-cost route from every included cell to the destination or target cell. Rees (2004) notes three points to be aware of when constructing a least-cost path using Dijkstra's Algorithm. The first, raised by Sedgewick (2001), is that the algorithm will work for all cases except where the cost of the path between two cells is negative. This must be avoided and is highlighted by the second point where it is stressed that an accurate choice and allocation of the cost function to the model is imperative. This would ensure that the cost between any two cells is positive. The third point raised describes the scenario where if two cells are identical in cost or weighting, then alternative but equal-cost paths could exist on any particular surface. The choice of one equal-cost path over another would, therefore, depend on the order in which the cells are processed (Rees, 2004).

Although the concept of Dijkstra's algorithm remains essentially the same, improvements have been made in recent years such as those presented in the following section.

2.1.3 Smart terrain (ST) algorithm

Yu *et al.* (2003) presented an argument for the superior performance of what is called the ST Algorithm by identifying weaknesses in existing algorithms for roadway route planning.

The investigation emanated from the fact that, due to existing algorithms which consider only adjacent nodes in generating the accumulated cost-surface, the potential for using bridges and tunnels is not considered and obstacles are commonly circumvented as a result, such as mentioned by Collischonn and Pilar (2000). On occasion, bridges or tunnels prove a more cost-effective option when the alternative is a long detour. Yu *et al.* (2003) proposed a new algorithm which is able to consider the linking of nonadjacent cells by extending contour lines between them. The example in Figure 2.1 is from Yu *et al.* (2003) and demonstrates the ST concept. The numbers in each cell indicates the elevation of a cell in meters while a contour line of 1000 m is traced across the grid. The cells over which the contour is traced are highlighted in yellow.

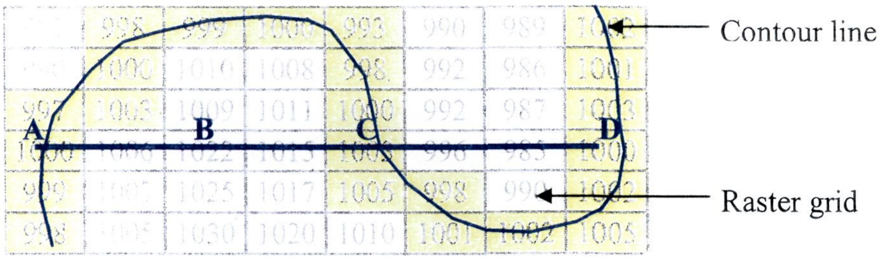


Figure 2.1 Contouring on a raster grid for bridge or tunnel determination (after Yu *et al.*, 2003).

There are two key assumptions made in the ST Algorithm. The first is that the start and end points of bridges and tunnels are at the same elevation. The second is that a straight line can be plotted between these points. These assumptions simplify the problem and reduce the estimated cost of construction. Although these assumptions are true in many cases, there remain certain circumstances where they are false, resulting in the estimated construction costs, per unit length, being inaccurate. This could potentially lead to a tunnel or bridge being incorrectly selected over a detour. Assumptions, therefore, need always be carefully considered and noted when analysing model results.

If Cell **A** in Figure 2.1 is assumed to be the new starting point of a least-cost path, then the aim of the algorithm is to link it with non adjacent Cells **C** and **D** of the same elevation. This is done in four key steps (Yu *et al.*, 2003):

Step 1. Initially the algorithm would scan the candidate cells around Cell **A** for adjacency. If there were no non-adjacent cells then the algorithm would continue to move along the contour line.

Step 2. The decision is then made by the ST Algorithm as to whether a bridge or tunnel should be added between any two non-adjacent cells (NAC's) on the contour line. Taking into account the assumption of a bridge or tunnel having no corners, the algorithm has then to consider all instances where a straight line between any two NAC's is intersected by the contour line only twice, including the two intersecting points. If this is satisfied then a bridge or tunnel is to be considered. Considering Figure 2.1, **AC**, intersecting the contour line at **A** and **C** only, would be considered for a bridge or tunnel but the line **A** and **D** would not as it intersects the contour line in the middle at **C**. **AC** is termed a *true connection* while **AD** is labelled a *false connection* and is not considered further (Yu *et al.*, 2003).

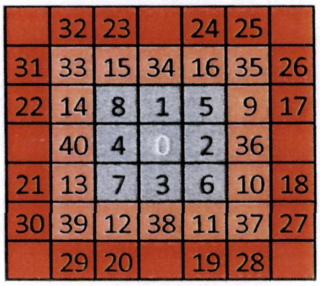
Step 3. A decision is then made by the algorithm as to whether a tunnel or bridge should be inserted by considering a random cell on a straight line between any two *true connections*. If the elevation of this random cell was found to be higher than the contour elevation of the start cell then a tunnel would be considered and the cost then calculated based on the distance between the two connections and the unit cost for a tunnel. The converse scenario applies. From the example in Figure 2.1, Cell **B** was selected between the *true connection* **AC**. With an elevation of 1022 m, Point **B** is higher than the 1000 m contour and a tunnel costing would then be evaluated. Once all the candidate NAC's for cell **A** have been assessed for their suitability, Cell **A** is marked and excluded from further searches and the cell with the next lowest base model value is selected. Step 1 is then reinitiated.

Step 4. By repeating Steps 1-3, an accumulated-cost surface is created. As with Xu and Lathrop (1995) and Lee and Stucky (1998), the least-cost route between two specified points can therefore be determined by following the back-link cells from destination to starting point.

The advantage of the algorithm presented above is that, included in this least-cost route, will be the addition of tunnels and bridges allowing for a more realistic and cost-effective route to be identified. In the development of the ST algorithm, Yu *et al.* (2003) made several noteworthy computational contributions to GIS route planning. The advancement came through improving the accuracy at which the distance between cell nodes are calculated *i.e.* considering the slope distance and slope direction between cells, thus analysing the terrain in three dimensions as opposed to two (Yu *et al.*, 2003; Saha *et al.*, 2005). This is discussed in detail in Section 2.1.4.

A problem with raster surfaces in GIS is that changes in direction of a path occur at right angles creating a zigzagged line where curves are intended (Douglas, 1994). Several authors such as Collischonn and Pilar (2000) and Douglas (1994) have attempted to reduce the cornering angle in order to smoothen a plotted path and produce more realistic results. More recent work on path smoothing has been carried out by Yu *et al.* (2003) and later by Saha *et al.* (2005) where a larger number of adjacent cells are included in the spreading function procedure and is detailed below.

The movement across a cost surface in a least-cost path procedure has been compared to the movement of chess pieces, *viz.* Rook, Bishop and Knight (Goodchild, 1977; Xu and Lathrop, 1994, 1995; Yu *et al.*, 2003; Saha *et al.*, 2005). Figure 2.2 and the accompanying text explain these moves as well as two additional movement types, *viz.* Knight31 and Knight32 (Saha *et al.*, 2005).



	32	23		24	25	
31	33	15	34	16	35	26
22	14	8	1	5	9	17
	40	4	0	2	36	
21	13	7	3	6	10	18
30	39	12	38	11	37	27
	29	20		19	28	

Figure 2.2 Increasing the search area of a spreading function has the effect of smoothing a route alignment's direction changes (after Saha *et al.*, 2005).

The various searching options from the centre 0 in the 3 * 3, 5 * 5 and 7 * 7 active cell matrixes in Figure 2.2 relate to chess moves as follows:

- Rook movement = cells 1 – 4, axis movement
- Bishop movement = cells 5 – 8, diagonal movement
- Knight movement = cells 9 – 16, two cells forward, one block left or right
- Kinght31 movement = cells 17 – 24, three cells forward, one cell left or right
- Knight32 movement = cells 25 – 32, three cells forward, two cell left or right.

In Figure 2.2, the cell 0 is activated and is in the process of searching its neighbouring cells for the one of lowest cost-of-passage. If only Rook and Bishop patterns are searched then any pathway created on the total friction surface (Section 2.1.2.1, Bullet 2) would only be able to change direction by 90° or 45° respectively. Similarly, by extending the search to the Knight pattern incorporating a 5 * 5 matrix, a direction change of 26.6° from either the X or Y axis is possible and is calculated in Equation 2.1.

$$\sigma = \tan^{-1}\left(\frac{\text{Horizontal distance}}{\text{Vertical distance}}\right) \tag{2.1}$$

where, σ = the change in direction of the corner.

Thus the 5 * 5 matrix allows for direction changes of 90°, 45° and 26.6° and a smoother traced path as opposed to the 3 * 3 matrix in the case of the Rook and Bishop patterns. The Knight31 and Knight32 patterns are additions by Saha *et al.* (2005) and extend the neighbourhood search to a 7 * 7 matrix as in Figure 2.2. These two patterns allow for 18.4° and 14.0° direction changes, respectively, as well as those in a 5 * 5 matrix. This has the effect of further smoothening the least-cost path, but will increase computational complexity (Saha *et al.*, 2005). As valuable as these improvements are, the smoothness of the path will ultimately depend on the resolution of the rasterised surface. Improvements in cost surface calculations are considered in the following section.

2.1.4 Cost surface calculations

Various calculations are considered in this section relating to the creation of an accumulated cost surface driven by the spreading function as described in Bullet 3 of Section 2.1.2.1. In order to derive an accumulated cost surface, several information types are required as listed by Saha *et al.* (2005):

- distance between cell centres (isotropic versus anisotropic surfaces),
- relative surface weight, and
- surface severity range (cost).

Xu and Lathrop (1995) described an isotropic surface as being one where a uniform cost, measured in any particular units, applies throughout a surface. On an isotropic rasterised surface a unit distance would apply to the width of a cell. Saha *et al.* (2005) presented an equation which is used in the generation of an accumulated cost surface and determines the cost of moving between two cells on an isotropic surface (Equation 2.2). The accumulated cost from a known start point to the activated cell is added to the cost of movement between the two cells in question in determining the accumulated cost surface (Yu *et al.*, 2003).

$$\mathrm{MCost} = \mathrm{DBC} \times \sum_{i=1}^{N} \mathrm{W_i x LC_i} \tag{2.2}$$

where MCost = the cost of movement between any two neighbouring cells,
DBC = the distance between any two cells,
W = the weight associated with each data layer
LC = the data layer cost.
N = Number of layers, and
i = layer number.

Weights are applied to each data layer to rank information from the most to the least critical, depending on any particular project's specific design requirements. As an example, slope may be deemed more critical in a canal design than land use and therefore provided with a higher rank. Saha *et al.* (2005) suggest an ordinal weighting system in the range of nine to zero, with 9 being assigned to the most critical data layer. In addition, each data layer is divided into categories relating to their severity and indicated by a cost. An anisotropic example of both weight and cost from Saha *et al.* (2005) is the breakdown of rock type into classes assigned on the difficulty or ease of excavation, blasting, and cut-and-fill works, as contained in Table 2.1.

Table 2.1 An example of lithology classes (after Saha *et al.*, 2005)

Rock type	**Weight**	**Cost**
Granite	4	6
Granite-Granodiorite-Gneiss		6
Schist and Gneiss		5
Quartzite with Slates		4
Limestone and Greywacke		3

In the route planning process for roads, canals and pipelines, slope and direction are critical factors, forcing designers to consider anisotropic surfaces (Collischonn and Pilar, 2000). In order to include this in the accumulated cost calculation, a gradient cost and weight has to be included in Equation 2.2 as well as an alteration for the distance (DBC) calculation to account for slope. If a Rook move is considered from cell 0 to cell 1, 2, 3 or 4 in Figure 2.2, the following equations may be used to calculate the distance between cell centres for both isotropic and anisotropic surfaces as presented by Yu *et al.* (2003) and Saha *et al.* (2005), respectively.

$$\text{Isotropic distance} = \mu \tag{2.3}$$

$$\text{Anisotropic distance} = \sqrt{\mu^2 + \left(H_{Pj} - H_o\right)^2} \tag{2.4}$$

where μ = Pixel size / cell width,

j = block 1 – 4 (Figure 2.2),

H_{Pj} = elevation of the connected neighbour cell, and

H_o = elevation of the active cell.

Note that the distance calculations are more realistic for anisoptropic surfaces because they consider the differences in elevation between each cell. Equation 2.2 is expanded to include gradient cost and severity level as shown in Equation 2.5 (Saha *et al.*, 2005). Note that DBC in Equation 2.5 represents the anisotropic distance between any two cells as determined using Equation 2.4.

$$\text{MCost} = \text{DBC} \times \sum_{i=1}^{N} \left[W_i \times LC_i + W_i \times G_i \right] \tag{2.5}$$

where G = gradient.

The use of anisotropic surfaces, as well as the reduction in corner angles of route alignments, are both major milestones in the development of route planning in GIS. The ability to circumvent an obstacle (Collischonn and Pilar, 2000) and the capacity to consider bridges and tunnels (Yu *et al.*, 2003) in a least cost path are marked improvements to spreading function procedures. It is important that weights are applied objectively to the various layers of spatial information so as to avoid "forcing" results according to a design team's perception of the anticipated output. The potential of GIS as a route planning tool is expanded upon in Section 2.2, where, several civil engineering aspects are incorporated in a route planning model.

2.2 Beirut Highway Alignment Model

Although the techniques used for the route planning of new roads, canals and pipelines are fundamentally the same, it was decided to consider the following GIS based highway route alignment model as several pertinent civil engineering concepts are well demonstrated. Lee and Stucky (1998) states that GIS projects need not necessarily be confined to route planning applications. Finding the optimal location for a quarry, park or depot, or predicting the environmental impact of a certain land use change can all be analysed with the same tools and techniques.

This case study was conducted to test a multicriteria decision-aid tool (MDAT) developed by Sadek *et al.* (1999) under real conditions. A 12 km section of highway outside the city of Beirut, Lebanon, was to be constructed from the town of Khalde to Damour. Three route alternatives were tested for ease of comparison, *viz.* South Mountain Highway (SMH), SMH-A1 and SMH-A2.

At the commencement of the project only the start and finish points were known and an unlimited number of additional routes could theoretically be tested with minimal additional effort and time.

2.2.1 Model construction

A route selection model was developed which used ArcView as the model interface and engine (Sadek *et al.*, 1999). AutoCIVIL, a software package that utilises AutoCAD and performs roadway design among other features, was linked to the model. This was done to incorporate its' powerful roadway design capabilities while slope-stability packages were also employed in an effort to develop a comprehensive model. Several programming languages were utilised to include these additions, such as,

- ARC/INFO and ArcView script,
- CAD (Computer-Aided-Design) script, and

- LISP (list Processing language) functions.

Once the user has created the database required for a specific study area, any number of constraining points need only be selected before the model is initialised to work through the various platforms in seven defined steps, as presented in Table 2.2 (Sadek *et al.*, 1999).

Table 2.2 Stepwise procedure of the multi-criteria decision aid tool to design and compare different road alignments (MDAT) (after Sadek *et al.*, 1999)

Step	Process
1	Consideration of soil and geological formations beneath the proposed route
2	Cut and Fill (C&F) analysis
3	Classify C&F into soil and geological functions
4	Plot C&F functions
5	Slope stability analysis and designation of Factor of Safety (FS)
6	Where FS $\leq$ 1.5 a file is created for analysis in a more advanced slope stability program
7	Summary report table produced

The results are output into four evaluation sections, which were used to compare the three route alignment options in this case study, *viz.*

- **Community disruption**: Consideration of the number of structures obstructing a route or within a prescribed minimum distance of a structure.
- **Environmental Issues**: Consideration of noise pollution from traffic volumes and is directly related to distance from the highway.
- **Geometric Design Issues**: This evaluation criterion considers both horizontal and vertical alignments analysed in AutoCIVIL and gives an indication of road safety. A route's specific length is also indicated here, as well as the number of necessary road structures, such as where fill depths become excessive warranting the construction of a bridge.
- **Geotechnical evaluation criteria**: Earthworks and slope stability are considered here.

The project engineer is able to use the ratings from these criteria to identify key areas where further or specialised design work is required.

2.2.2 Data requirements and methodology for the base model

Data collection for the base model of GIS projects is often the most time consuming phase, and this case study was no exception. Due to the Lebanon War from 1975 to 1990 there was limited availability of digitised spatial information and many hardcopy maps were out of date and without sufficient detail (Sadek *et al.*, 1999). The result of this lack of quality information prolonged this phase of the project by approximately one year as new maps were created and existing ones updated.

The base model required digitised information on the following: roads, cities, towns, villages, land cover, land use, geology, soil, rifts, depth to water table and topography. It must be noted that the final output of any model is only as accurate as the information collected and entered in the base model and hence it is important to treat the outputs of such models with caution. It is recommended by Sadek *et al.* (1999) that the output from this particular model be used as a comparative tool for route selection purposes and only as a reference for the final design calculations.

Once the data had been collected and the base model compilation was completed, the users merely had to indicate the start and finish points, as well as other compulsory highway intersections, and the model ran automatically through the seven described steps (Table 2.2).

2.2.3 Summary of results

Three potential route alignments were compared in the model, the results of which are displayed in Table 2.3. The four evaluation criteria are highlighted in grey with specific criterion listed below each of the four categories on the left of the table. Displayed in the three columns on the right of the table are the results for the three routes being compared namely, SMH-A2, SMH and SMH-A1.

Table 2.3 Summary of model outputs enabling a direct comparison between the three specified routes of the Beirut highway (after Sadek *et al.*, 1999)

CRITERIA	SMH-A2	SMH	SMH-A1
a) COMMUNITY DISRUPTION			
Number of structures within road width + 10 m	13	12	1
b) ENVIRONMENTAL ISSUES - NOISE			
Number of structures within edge of road + 150 m	315	102	65
c) GEOMETRIC DESIGN ISSUES			
Number of horizontal curves with radii < 200 m	6	7	7
Cumulative length of route segments (m)			
0 - 5 % slope	12 053	11 405	8 030
5 - 8 %	0	1 268	4 182
> 8 %	0	no data	1 428
Total route length (m)	12 053	12 673	13 640
d) EARTHWORKS / GEOTECHNICAL			
Slope stability			
Number of sections with FS < 1.0	0	0	8
Number of sections with 1.0 < FS < 1.5	0	0	11
Cut and fill (m^3)			
Cumulative cut volume	3.06 x 10^6	4.38 x 10^6	6.35 x 10^6
Cumulative fill volume	3.82 x 10^6	4.05 x 10^6	17.19 x 10^6
Potential number of road structures	9	9	12

Table 2.3 indicates that SMH-A1 interferes with only one structure and is the cause of less noise pollution than SMH-A2 and SMH. The trade-off is that this route is almost one kilometre longer than SMH and one and a half kilometres longer than SMH-A2, which is the most direct route. SMH-A2, being the most direct route is, however, responsible for the largest community disruption and by far the highest noise polluter. The engineer can use these results to select the most appropriate route under project specific constraints. These results, as well as others provided by the model's final output, can be used as a starting point for the final design.

2.2.4 Conclusions

A multicriteria decision-aid tool (MDAT) was used to evaluate the most appropriate of three potential highway routes between the town of Khalde and Damour in Lebanon (Sadek *et al.*, 1999). Various criteria were used to evaluate the suitability of each route by direct comparison as in Table 2.3. Only three routes were tested for ease of comparison, however,

the model is capable of processing many routes simultaneously, therefore allowing for a comprehensive search for the optimum route between two or more points to be conducted (Sadek *et al.*, 1999).
The model does not remove the need for civil engineers and other construction professionals but merely enables the design team to rapidly analyse and directly compare a large number of alternatives. This ensures that the most efficient solution is selected according to specific project requirements. Sadek *et al.* (1999) warned that the output from such a model should be used as a means of comparison rather than as exact design values.

The data collection and construction of the base model for this project took approximately one year to complete. However, with the increasing availability of digitised imagery and land cover information this time will be cut down dramatically in future projects (Sadek *et al.*, 1999). Any GIS model is only as good as the information entered and for that reason digital maps should be continually updated to maintain accuracy and to ensure readily available information for the future. Further to this the accuracy of the base model, and ultimately the model output is subject to the resolution at which the data is captured.

Although GIS route planning is not yet at the stage where route alignment can suffice as a final road design, Sadek *et al.* (1999) have comprehensively demonstrated the potential of GIS as a route planning tool.

2.3 Discussion and Conclusions

It is evident that GIS as a route planning tool is superior to traditional route planning techniques in many respects. It offers the advantage that algorithms, applied in a GIS environment, are able to consider every possible route alignment between two or more selected points in space and indicate the most cost effective route according to a number of optimisation criteria. A large quantity and variety of spatial information can also be processed simultaneously due to the nature of information overlaid in a GIS interface. This supersedes previous methods where maps and additional data had to be considered separately. The primary cost minimisation technique applied by algorithms in GIS is to avoid costly obstructions, such as river crossings, steep slopes and existing infrastructure.

The algorithms proposed by Dijkstra (1959) set the stage for modern route planning in GIS and has been modified little in principle over the last half-century. Several additions have, however, been made to either improve efficiency or to include additional features, such as consideration of bridges and tunnels in routing solutions.

It can be concluded that, despite advancements in the field of route planning in GIS, these methods are still only as effective as a route selection and comparison tool and have not developed sufficiently for model outputs to be utilised for final civil design purposes. It is, therefore, still critical to include road design professionals in any road alignment project from model design through to auditing the output.

In all GIS models, assumptions have to be made, and with assumptions there are exceptions which could affect the accuracy of model output. In the construction of new models it is therefore imperative that all assumptions have adequate justification and are acknowledged when presenting model output. It is also important to the accuracy of model output that weights are applied objectively to the various layers of spatial information so as to avoid "forcing" results according to a design team's perception of the anticipated output. GIS models are only as accurate as the information entered, thus an improvement in the spatial resolution of data would have the desired effect of improving the precision of model output.

From the literature reviewed it is clear that route planning in GIS has a wide scope of application and is effective within the bounds of valid assumptions. Advances in both route planning algorithm thoroughness and the computational ability of modern computer processors provide a robust platform with which to plot optimal route alignments according to a large variety of design criteria.

3 MODEL DEVELOPMENT

The transport sector of the sugar supply chain contributes approximately 25 % to the total production costs of the industry. It was hypothesised that a GIS based infrastructure planning model could assist in reducing these transport costs. The FastTrack transport infrastructure planning model is a generic model developed within ArcGIS 9.2 to fulfil this role. It incorporates inputs, such as road construction and maintenance costs, terrain and land-use maps, vehicle performance specifications and annual sugarcane volumes in order to mathematically determine the most cost effective route from a production region to the mill. The alignment of existing roads and the potential for new specialised roads are simultaneously considered. The aim of the chapter is to describe FastTrack and the different assumptions made during the model development.

3.1 Model Input

All input data are entered on a per pixel or unit area basis, based on a set annual volume of harvested sugarcane, a desired Capital Expenditure Repayment Period (CERP) and design and performance specifications of each particular vehicle type. All inputs (represented in blue in Figure 3.1 and Table 3.1) are manipulated and reclassified within the model through a series of calculations. All inputs are discussed in general terms in this section. Details of gathering and organising the data will be considered more closely in Chapter 4 during a case study.

The road maintenance costs layer (I1, Figure 3.1 and Table 3.1) includes the annual cost of maintaining various types of roads in a study area, including, maintenance of any new roads that are to be built. Maintenance costs are normally affected by several factors, such as geographic location and the proximity to a source of quality aggregate material, soil types, road gradient, drainage, number of culverts and significantly, the type and volume of traffic operating on the road. Users of FastTrack need to use location specific values and, where these are unavailable, conservative best guess estimates, based on the type and volume of traffic, will suffice for initial investigations.

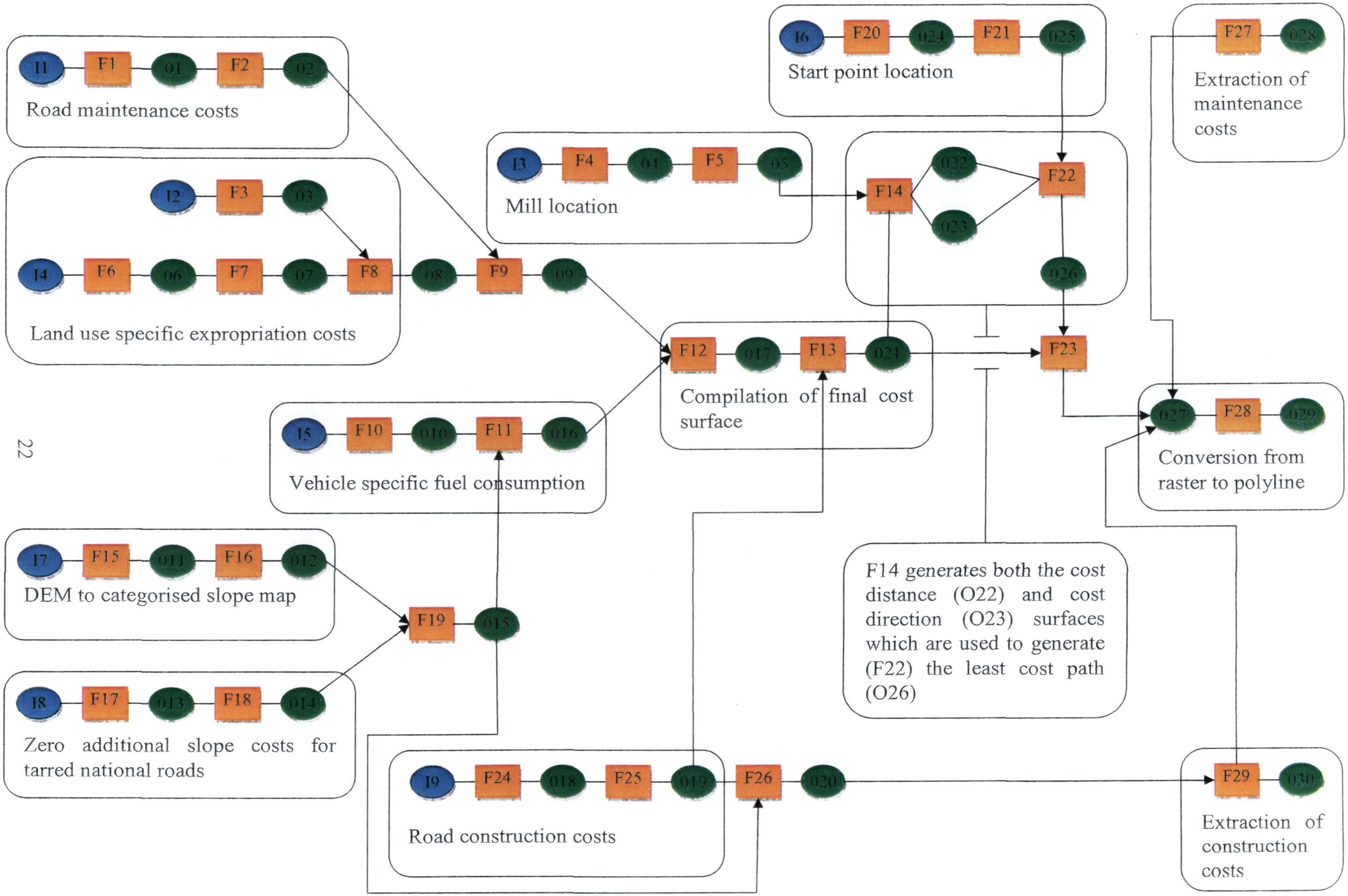


Figure 3.1 The FastTrack model flow diagram showing inputs, functions and outputs. The codes within the individual shapes refer to Table 3.1.

Table 3.1 Inputs, functions and outputs for the FastTrack model. The reference column can be used to identify each particular section of the model in the model diagram on the previous page (Figure 3.1)

Type	Reference	Discription
Input	I1	Road maintenance costs
	I2	Landuse specific expropriation costs
	I3	Mill location (destination)
	I4	Road purchase cost
	I5	Vehicle season average fuel consumption
	I6	Start point (point of departure)
	I7	Digital Elevation Model (DEM)
	I8	Zero cost to tarred regional routes
	I9	Road upgrade and construction costs
Function	F1,F6,F17,F24	Convert polyline to raster
	F3,F4,F10,F20	Convert polygon to raster
	F15	Convert DEM to slope map
	F2,F5,F7,F16,F18,F21,F25	Reclassify raster values
	F26,F9,F11,F12,F13	Addition
	F8,F19	Multiplication
	F14	Cost distance/direction
	F22	Least Cost Path (LCP)
	F23,F7,F29	Extract by mask
	F28	Convert raster to polyline
Output	O1-O30	Output layers
	O21	Cumulative cost surface
	O28	Total per trip maintenance costs
	O29	Final route alignment
	O30	Total per trip construction costs

Land use specific expropriation costs (I2, Figure 3.1 and Table 3.1) are applied to a detailed land use map. These values are based on regional norms, except where specific costs are known. This layer requires significant user input, especially where detailed land use maps are not available. Aerial photography of a suitable resolution can be used to manually digitise the boundaries of the various land use types.

The mill location is a layer created by the user (I3, Figure 3.1 and Table 3.1). It is used by the cost distance / direction function (F14), which are both required in the generation of a least cost path (LCP), (F22, O26). The start point also needs to be input (I6, Figure 3.1 and Table 3.1) and can be an existing or potential depot site, or a natural haulage flow point where all sugarcane from a specific area will pass over.

The road purchase cost layer (I4, Figure 3.1 and Table 3.1) is based on the assumption that any land occupied by an existing road, carries a zero cost of purchase. The FastTrack model is therefore encouraged to identify route alignments where existing roads are either immediately suitable or could be upgraded and utilised. Alternatively and depending on the density of the existing road network, the FastTrack model may identify a more cost effective new and more direct route.

A critical component of the model in terms of vehicle comparison is the accurate estimation of a vehicle's season average fuel consumption (I5, Figure 3.1 and Table 3.1). It was decided that season average fuel consumption figures would provide a more accurate means of gauging the fuel cost of a vehicle rather than adding a terrain-specific fuel costing module to FastTrack. Users need to gather information from vehicle manufacturers, such as the most fuel efficient travel speed, maximum slope and payload limitations, purchase price and expected vehicle utilization, among others. It is useful to compare manufacturer information with hauliers operating over similar terrain and lead distances in order to confirm or adjust values where necessary. Season average values incorporate all the variations in a mill season including operating in a variety of weather conditions, road traffic and sugar mill queue delays, and differences in driver skill level and attitude.

In raster GIS, the spatial accuracy of a combination of layers is affected by the layer with the lowest resolution. It is important that relatively small features, such as pylons, which would be unnecessary and costly items to relocate, are considered and avoided by any new road alignment. It is therefore recommended that the Digital Elevation Model (DEM – I7, Figure 3.1 and Table 3.1), which is a vital layer, be of a resolution of 10 m * 10 m, or finer. The DEM is converted to a slope map and is subsequently categorised into several slope ranges, which either affect or have no consequence on average road construction costs.

The input I8 (Figure 3.1 and Table 3.1) ensures that additional slope-dependent construction costs are not applied to existing national tarred roads. The reference to national roads here includes all tarred roads under the control of the relevant regional roads authority and it was assumed that additional private construction work would not take place on these. National roads within a study area should be analysed separately to determine whether there are any sections on these roads where the gradient exceeds that of the hill climbing capability for a specific vehicle type or configuration. Additional costs need to be applied on these sections to ensure that a realistic economic estimate is reached.

Road construction and upgrade costs (I9, Figure 3.1 and Table 3.1) are considered in a critical and region specific layer in the model. These costs should be based on area averages and several independent best estimates are required to ensure that the layer is both consistent and conservative. It was decided that area average construction costs would be assumed instead of considering all the compounding factors, such as soil type, culvert design, availability of quality aggregate and the distance to quarry sites. Paige-Green (2008) confirmed that tenders for road construction are often calculated using average road construction costs due to the large number of variables and the complexity of the relationships between these and the actual construction costs. The average cost would include typical cut and fill volumes, which would only vary significantly if the terrain were particularly flat or steep, where excessive earthworks and culverts will be required. These categories are also influenced by a particular vehicle's climbing ability, ensuring that the vehicle would be able to maintain a constant and fuel efficient speed on any new road that the FastTrack model recommends.

3.2 Functions and Output

All inputs are manipulated and reclassified within the model through a series of functions (represented in yellow in Figure 3.1 and Table 3.1) which result in outputs (represented in green in Figure 3.1 and Table 3.1).

Once the cumulative cost surface, O21 (Figure 3.1 and Table 3.1), has been created, the FastTrack model makes use of the *least cost direction / distance* surface generating function within ArcGIS 9.2 (discussed further in Section 3.3), which is based on Dijkstra's (1959) shortest path algorithm. This function considers the cumulative cost surface as well as the destination location and creates the cost distance and cost direction surfaces. A cost distance layer is a raster surface representing the lowest combined cost from each cell to the nearest destination point (McCoy and Johnston, 2001). In the FastTrack model the destination is the sugar mill. Each cell in a cost direction layer has a numerical value assigned to it, according to the direction to the closest surrounding raster cell along the cumulative LCP to the source

(McCoy and Johnston, 2001). A detailed account of LCP theory and its various applications can be found in Chapter 2.

The LCP function utilises the cost direction and cost distance layers as well as the user input start point location to identify the alignment of the most cost effective route from the start point to the mill. This alignment is used in a second and independent step to extract the cumulative cost as well as separate infrastructural and road maintenance costs payable per trip (F23, F27, F29 in Figure 3.1 and Table 3.1).

Model results are output as the charge a vehicle would incur, per consignment, if infrastructural improvements were to be repaid within the stipulated CERP. In other words results are output as the sum of the cost of each pixel crossed on the devised path from the designated starting and finishing points, including road maintenance charges and fuel expenses. In order to compare various transport scenarios, the model results are required to be multiplied by the number of consignments necessary to transport a set crop volume, within the limited number of days allocated to the milling season. This is a post processing operation and is discussed further in Section 4.3.

In order for a user to differentiate between different transport systems and new routes, it is recommended that an economic analysis of the transport system be conducted and the results be considered in conjunction with the output acquired from the model. These analyses are discussed further in Section 4.3.

3.3 Software Implementation

ArcGIS 9.2 is an extensive GIS platform created by the Environmental Systems Research Institute (ESRI) and offers a wide range of geospatial tools. The modelling tools offered in ArcGIS 9.2 are easy to use where all available functions can be dragged into, and linked together within the modelling window. This allows for extensive spatial models to be created and modified. The FastTrack model was created in this manner and users will be required to use the model in conjunction with an ArcGIS 9.2 user licence. General GIS experience and a working knowledge of ArcGIS 9.2 and Microsoft Office systems are also required.

Numeric values to all FastTrack inputs, from region and vehicle specific data gathered by the user, are generated in Microsoft Excel. The outputs from these tables are entered directly into the model. A summary of model input values is located in Appendix A.

3.4 Model Verification

Utilising data from the case study which is further described in Chapter 4, each branch of the FastTrack model was excluded independently, in a systematic procedure to verify model performance. The model was run repeatedly in this manner in an effort to identify inconsistencies and consequently to verify the operations of the model. In all cases the FastTrack model behaved predictably. In addition, the reclassification of raster values (Figure 3.1 and Table 3.1) were manipulated to test the sensitivity of these on the model output. In all cases notable output variations only occurred when the reclassified values were altered significantly. A large number of model runs were performed in this process with predictable results. In order to not dilute the results presented in Chapter 5 and due to the repetitive nature of the verification procedure, it was decided that further elaboration was to be excluded.

3.5 Conclusions

A wide range of input variables dictate whether a more direct route to the mill should be constructed, or whether it is more cost effective for haulage vehicles to operate on existing national roads. These inputs range from general and slope dependant construction costs to land use, road maintenance and vehicle performance characteristics, and are logically organised in a series of tables within Microsoft Excel. Inputs are calculated on a per trip basis with the premise that all infrastructural improvements are to be repaid within a predetermined capital expenditure repayment period (CERP).

Model output should therefore be multiplied by the number of trips necessary to transport the set volume of sugarcane within one milling season. The FastTrack model is based on a framework of spatial calculations within ArcGIS 9.2 (Figure 3.1), which culminate in the determination of a least cost path (LCP) from start point to mill for each vehicle configuration.

An economic analysis of total transport system costs is required if the vehicle configurations selected are to be compared directly. This should be completed externally to the GIS environment and is discussed further in Section 4.3.

After a rigorous verification process it was concluded that the model behaved predictably under a wide range of input variables and reclassification scenarios. The FastTrack model, therefore, ensures that the route selected is the optimum route in terms of vehicle and infrastructural utilisation efficiency and economics.

4 DEMONSTRATION OF THE FASTTRACK MODEL: CASE STUDY - METHODS

4.1 Introduction

The Noodsberg mill region is located in the KwaZulu-Natal Midlands in South Africa (Figure 4.1). It is a major sugarcane producing region crushing approximately 1.45 million tons of sugarcane per annum which relates to 150 000 tons of sugar. All of the harvested sugarcane is transported to the mill by road with sugarcane supply areas being located as far as 70 km away. More than 60 % of the finished product, including 70 000 tons of molasses, is transported to Durban by road, while the remainder of the sugar is transported to Germiston by rail. Noodsberg is a well established agricultural region with the majority of farms being commercial. Several towns are situated in the area, including Wartburg, Harburg and Dalton, which are linked by a network of regional and district roads on which the sugarcane is transported to the mill.

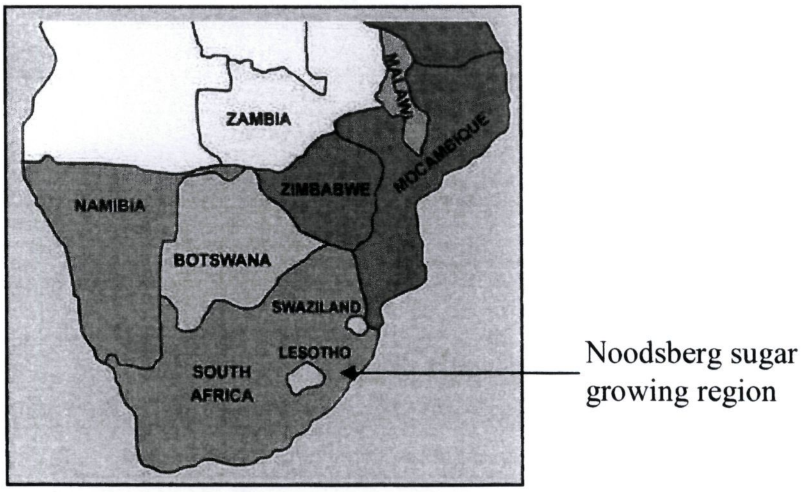


Figure 4.1 Location of the Noodsberg sugar growing region in Southern Africa.

The region was selected for the case study by virtue of the mill's close proximity to the University of KwaZulu-Natal and the large volume of sugarcane transported by road. The aim of the case study was to test FastTrack with real data to demonstrate its capabilities. It was decided that a small portion of the region, with minimal data collection requirements but with multiple land uses and an integrated network of farm and national roads, should be selected to exhibit the model's potential.

Two common vehicle configurations and a third, utilised by sugar industries in other countries, but not common to the region nor legal on South Africa's roads, were selected to compare FastTrack's infrastructural planning capabilities. Apart from fuel costs, FastTrack does not consider any of a vehicle's additional system costs, like ownership, operational and labour costs. The model is also not used to determine the number of vehicles required to haul a set volume of sugarcane to the mill within the limited milling season length. In order to compare FastTrack's infrastructural routing solutions, in terms of these additional system costs, an economic analysis was conducted on the results for the three vehicles. The methodology of this analysis as well as that of a sensitivity analysis, also conducted on FastTrack's results, are included in this chapter. Results of the case study and the economic and sensitivity analyses are detailed and discussed in Chapter 5.

4.2 Input Data and Assumptions

Included in this section is an account of all the input data collected for the case study area and the selected haulage vehicles.

4.2.1 Case study description

Figure 4.2 is a land use map of the study area, which represents only a small portion of the Noodsberg sugar growing region. Represented by an orange square is the location of the Noodsberg sugar mill while the start point, represented by an orange circle, indicates the position of a natural haulage flow point. It is assumed that all sugarcane hauled from the region south of the start point (Area B) will flow through or near this point, as indicated by the arrows in Figure 4.2. Area B comprises of approximately 1750 ha of commercial sugarcane. The cool and dry winter conditions within the area suppresses sugarcane growth and the crop of approximately 140 000 tons is normally harvested on a 24 month rotation. It is assumed that the crop is staggered so that approximately half is harvested and hauled to the mill for crushing annually.

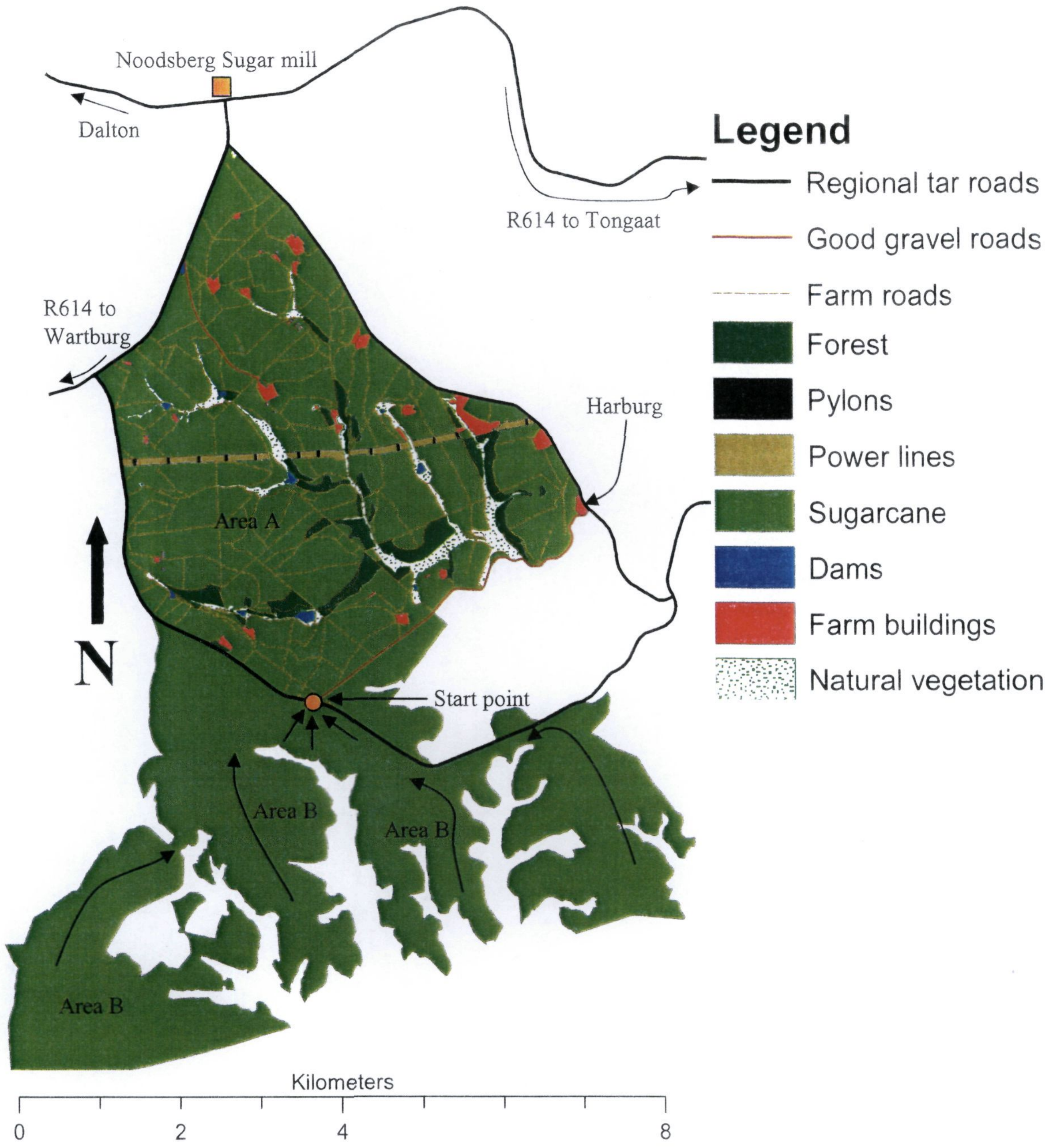


Figure 4.2 Land use map of the case study area showing Areas A and B and the location of the start point and the Noodsberg sugar mill.

It was decided that only the volume of sugarcane from Area B would be considered in the case study. Benefits to sugarcane growers between the start point and the mill (Area A) as a result of potential infrastructural improvements were not considered. Area A was, therefore, modelled in FastTrack in terms of terrain, land use, road construction and road maintenance costs with respect to the volume of sugarcane from Area B only. A number of land uses exist within Area A, as shown in Figure 4.2. Table 4.1 contains the area occupied by each land use and the associated expropriation and additional construction costs for a particular feature within Area A, through which any potential new road infrastructure would pass. The expropriation cost is represented in *R / ha* as these costs are more easily understood in these units. The additional construction costs represented in *R / pixel* with a standard pixel size for all layers based on the 10 m * 10 m resolution of the digital elevation model (DEM). This represents the construction cost or exaggerated construction cost as detailed below the table. All values are required to be converted into *R / pixel* values before being entered into FastTrack.

Table 4.1 Land use types, the area occupied by each and the expropriation and additional construction costs within Area A near Noodsberg, South Africa

Land use	**Area (ha)**	**Expropriation cost (R/ha)**	**Additional construction cost (R/pixel)**
Sugarcane	1795	30000	
Forestry	131	23000	
Farm buildings	47	2000000	
Dams	9		2000000
Natural vegetation	103		50000
Pylons	3		3000000
Powerlines	31	30000	

In Table 4.1 the column "Expropriation cost", refers to the once-off cost required to purchase the land, based on the current land use through which a proposed new road passes. "Additional construction costs" in Table 4.1 refers to the cost to construct on or across a particular land use. Extremely high costs were given to both dams and pylons as it was assumed that a large high voltage pylon would not be moved or a bridge be constructed over a small farm dam to allow for a new haulage route to pass through. After considering aerial photography of the area, it was found that all "natural vegetation" within the study area, were either wetlands or riparian zones. The associated natural vegetation cost, as depicted in Table 4.1, therefore, includes the cost of a low level crossing based on the average cost for a 20 m long crossing amounting to approximately R 100 000 (Pike, 2008). It is recommended that any proposed alignments passing through such areas should be subject to further investigation and an environmental impact assessment.

As discussed in Chapter 3, capital costs are spread out over the capital expenditure repayment period (CERP), which for the case study was assumed to be 5 years. All costs are divided by the total number of consignments required to haul a set volume of sugarcane, for a particular vehicle type. This ensures that all cost surfaces are added within FastTrack on a per trip basis.

It should be noted that Farm buildings (*cf.* Figure 4.2) include the space in between adjacent buildings and all fenced off areas, such as private gardens and vehicle workshop yards. It was assumed that these areas would not be considered for the alignment of any new roads and an exaggerated expropriation cost was, therefore, assigned to these to ensure that a realistic solution was selected by FastTrack.

4.2.2 Road construction and maintenance

A gravel road of 10 m in width was selected for the construction of any new roads within the area. The cost of construction is R 300 000 km^{-1} plus a preventative maintenance plan with a cost of R 20 000 $km^{-1}.an^{-1}$ (Oloo, 2008; Paige-Green, 2008; Pike, 2008).

Resurfacing, which depends on numerous variables, such as traffic volume, drainage and the quality of the aggregate used, would normally be required after 6 years (Paige-Green, 2008). As the repayment period was set at five years, it was decided that this additional cost would not be included in the study.

4.2.3 Vehicle data

The current haulage to Noodsberg mill comprises of a range of vehicle-trailer combinations. The most commonly used vehicles are the interlink, the rigid haulage tractor / tractor hilo and the rigid draw bar truck with different trailer combinations. In order to demonstrate the capabilities of FastTrack, three distinctly different vehicle types were selected and compared, *viz.*

- A tractor hilo – Bell 1866 AF (*cf.* Figure 4.3),
- A land train – Bell $2306D_{4x4}$ (*cf.* Figure 4.4), and
- An interlink – Mercedes-Benz Actros 3350 / 33S (*cf.* Figure 4.5).

A land train type, not currently utilised at Noodsberg and not permitted on public roads in South Africa, was included to expand the range of haulage vehicles tested and to demonstrate the flexibility of the model by forcing it to consider route alignments off public roads.

TRACTOR HILO

The Bell 1866 AF, fitted with a standard sugarcane trailer supported on a walking beam axle with tyres set at 6 bar was selected as a first vehicle type (Figure 4.3). In this region the selected trailer configuration has an average payload of 14.3 tons. Approximately 39 of these vehicles currently operate in the Noodsberg region and are responsible for hauling 217 000 tons or 20.4 % of the annual crop. The vehicle is characterised by relatively fast road speeds, excellent infield capabilities and a single material handling regime. Fuel consumption of the Bell 1866 AF operating over similar terrain and with the same payload and lead distance is approximately 60 l per 100 km (Lyne, 2008).

Figure 4.3 A Bell 1866 F with a typical walking beam axle trailer. The 1866 AF is the front wheel assist version of the 1866 F.

The Bell 1866 AF is commonly used when haul distances are less than 15 km (Lyne, 2008). Lyne (2008) indicated that it is generally more cost effective to double handle sugarcane using an infield tractor in combination with an interlink or rigid drawbar truck for distances greater than 15 km. This is based on the fact that, as haulage distances increase, vehicle efficiency and speed becomes more critical factors.

When fully loaded, the Bell 1866 AF can maintain a speed of 30 km.h^{-1}, which is only significantly affected by slopes above 8 % (Bell Equipment, 2007). In order for routes to not include slopes that will exceed 8 %, additional construction costs are applied to such slopes (*cf.* Section 3.1).

LAND TRAIN

Land trains are used successfully in several countries around the world, including Malawi, Australia and Argentina. The vehicle is four-wheel driven and articulated allowing for good infield manoeuvrability. Low levels of soil compaction and stool damage can be attributed to large high floatation tyres inflated to 2 bar, fitted throughout the rig. The trailers are supported on a walking-beam axle, which assists in driving on uneven terrain. The trailers have no suspension, which can cause vibrations through the rig when driving at high speeds on well surfaced roads (Prinsloo and Hayworth, 2008).

Figure 4.4 A Bell 2306D$_{4x4}$ pulling six trailers in a field in Malawi (Prinsloo and Hayworth, 2008).

Payloads of 57 tons can be hauled to the mill in six trailers at reasonable speeds of 19 km.h^{-1} laden and 28 km.h^{-1} empty. The gross combination mass (GCM) of the particular land train modelled is approximately 110 tons. The maximum permissible GCM on South Africa's roads is 56 tons (Fleetwatch, 2007). With such a disparity between the legal weight and that of the land train combination, a significant fine was imposed in the model in the form of a maintenance charge for travelling on national roads.

The vehicle trailer combination is limited by slopes above 8 % (Prinsloo and Hayworth, 2008), but it was conservatively decided to restrict the model to slopes of 7 % and below. Slopes above 7 % were assumed to incur additional construction costs, to cover the necessary cutting and filling. The 7 % restriction on all potential land train roads will ensure that both the speed and efficiency of the vehicle are maintained. As infield and loading considerations are not considered in much detail in the model, a post modelling assessment of loading areas for a particular region may be required. Fuel consumption of the Bell 2306D operating with the same payload and lead distance was increased by 15 % to account for the undulating terrain within the region. The value used was 78 l per 100 km (Prinsloo and Hayworth, 2008).

INTERLINK

Within the Noodsberg region, interlinks are responsible for hauling approximately 34 % of the region's sugarcane to the mill using thirteen vehicles. The type of interlink that was selected for the project was the Mercedes-Benz Actros 3350/33S truck tractor fitted with an Afrit tandem/tandem axle sugarcane interlink combination trailer set (Figure 4.5).

Figure 4.5 A Mercedes-Benz Actros 3348 sugarcane interlink.

Lyne (2008) stated that the infield use of interlinks should be avoided wherever possible due to high tyre pressures (± 6 bars), which can cause severe soil compaction and stool damage, especially under wet conditions (Van Antwerpen *et al.*, 2000). As a result, interlinks are most commonly loaded at specially prepared loading zones adjacent to sugarcane fields. This requires sugarcane to be extracted to the loading zones, by an infield tractor and trailer. The sugarcane is transloaded into an interlink using a standard three-wheeled cane loader. As a result of the double handling nature of interlink haulage, it is generally considered that only lead distances of greater than 15 km are more profitable compared to a single handling system, such as that of the tractor hilo (Lyne, 2008).

Despite the large engine capacity of an Actros, it is an efficient vehicle capable of average speeds of 60 $km.h^{-1}$ empty and 40 $km.h^{-1}$ laden with fuel consumption being approximately 65 l per 100 km (Lyne, 2008) on slopes of less than 10%. These figures vary according to terrain, traffic obstructions and flow and lead distances. Due to the fast road speed and large consignment capacity of approximately 32 tons, interlinks are well suited haulage vehicles for the sugar industry.

4.3 Economic Analysis

FastTrack was used to delineate the optimal route for each vehicle configuration and an economic analysis was conducted to assess total system costs associated with each selected route. This was used to identify which system would accrue the lowest cost in hauling the set volume of sugarcane from the start point to the mill.

A commercially available costing model, based on sound logistics principles and economic fundamentals was utilised for this purpose (Bell Equipment, 2008). Figure 4.6 details the basic flow of costs through the economic model while a detailed table including all costs is located in Appendix B. Management costs were assumed to be equal for the three systems and were therefore excluded from calculations. Output from the model, therefore, allows for a direct comparison of the differential costs between the three systems. Total annual vehicle costs (light grey shaded, Figure 4.6) were added to construction and maintenance costs derived from each FastTrack routing solution to determine a total system cost (dark grey shaded, Figure 4.6) for each vehicle type.

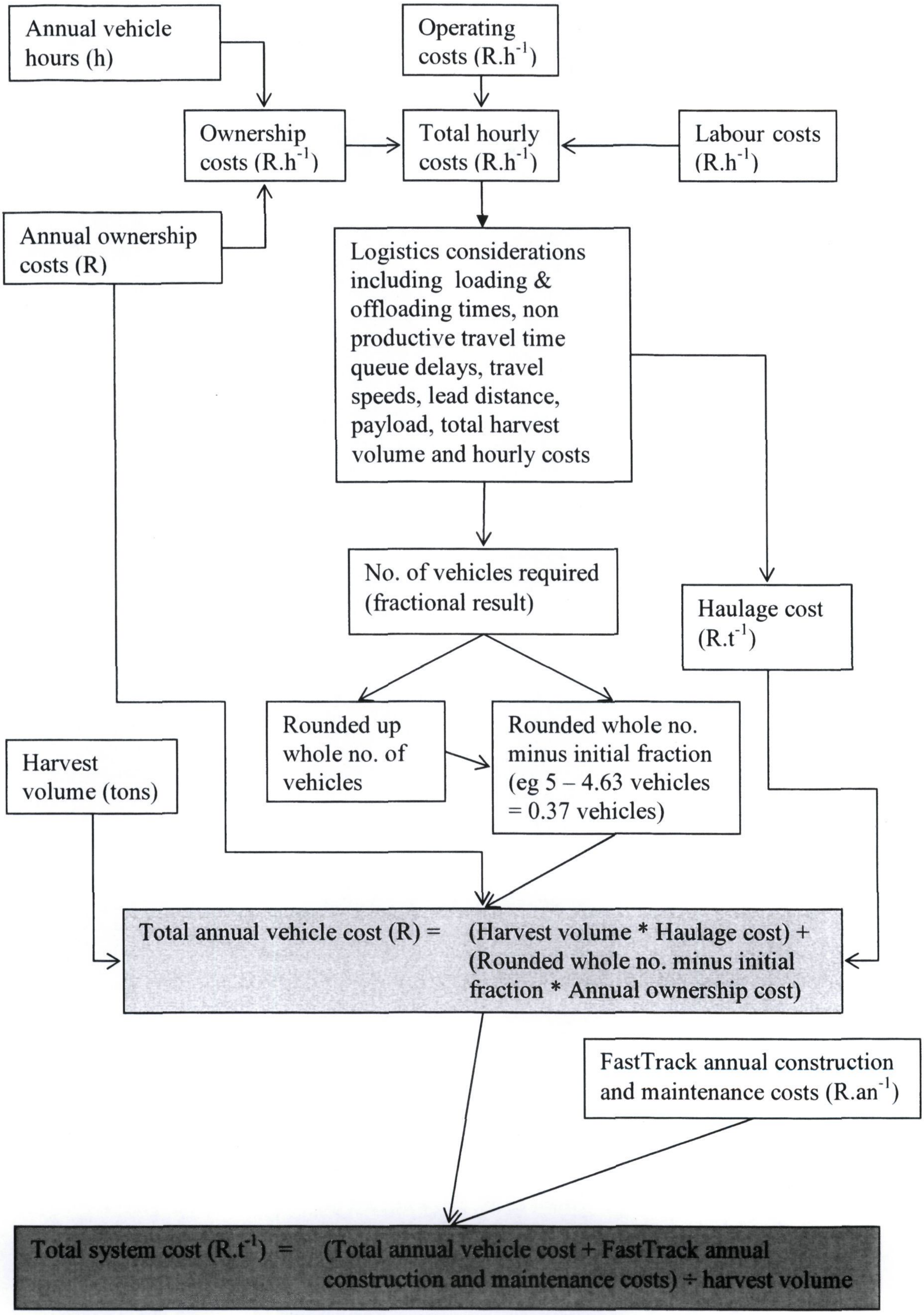


Figure 4.6 Basic flow of costs through the commercially available costing model used to compare differential costs of the three haulage systems.

The general operating costs of a vehicle differs depending on the quality of the road surface on which the vehicle drives (Lyne *et al.*, 2005). These costs were therefore collected based on the type of surface each vehicle was likely to operate on within the case study area. As an example and excluding haulage from within specific farms in Area B (*cf.* Figure 4.2), interlinks and tractor hilos hauling through the start point to the mill would drive on tarred roads. Operational costs relating to these two vehicles, therefore, reflected this. Land trains would only drive on newly constructed or upgraded gravel roads and thus appropriate operational costs relating only to the use of land trains on gravel roads was collected and utilised.

A detailed calculation of ownership costs was performed which included consideration of vehicle and trailer costs, residual value, vehicle availability, the number and length of shifts worked, interest rates licence and insurance fees among others. All capital expenditure was calculated excluding value added tax (VAT). The decision was made that the entire system would work on a 5 year capital expenditure repayment plan (CERP). It was assumed that new vehicles would be purchased with zero initial capital and were expected to hold a 20 % residual after 5 years (Ortmann, 2008) while the trailers are assumed to retain a residual of 50 %. The annual ownership cost for each vehicle was divided by each vehicle's annual operating hours to determine the cost of owning the vehicle per operating hour.

The predominant operating cost is fuel usage, which was calculated in terms of litres per hour. These figures, as with all input data, were acquired from industry where vehicles operate under similar lead distances, terrain and road surfaces. Oil, tyre and maintenance costs were included in the calculation of the total operating cost for each vehicle configuration. Tyre cost can be a significant contributing variable. In the land train scenario, for example, where the prime mover has four wheels and its' six trailers have twenty-four wheels, total tyre replacement costs are approximately R 616 000. This occurs approximately every 4000 hours except for the front wheels which are replaced approximately every 3000 hours (Prinsloo and Hayworth, 2008).

Only the cost of the driver per vehicle was considered in the determination of total labour costs. Drivers were assumed to be paid R 167 per shift, which accumulates to approximately R 4000 per month considering a six day working week.

Adding ownership, operating and labour costs will resulted in an hourly cost per vehicle. However, to determine the number of vehicles required and therefore the system cost excluding construction and maintenance costs associated with each routing solution, several other variables also needed to be considered. These included, total annual crop volume, loading time, vehicle speed - loaded *vs.* unloaded, offloading time, vehicle delays and unproductive periods. To standardise loading time, a super zone was assumed at the start point with loading times being determined by the number and capacity of the trailers to be filled. All these variables influence a vehicle's per shift haulage productivity, which, when multiplied by the total annual shifts worked, relates to a total achievable annual haulage capacity per vehicle type. The total annual production was divided by this value to determine the total number of vehicles required. If the result included a fraction of a vehicle, then the difference between the next ascending whole number and the fractional result was required to be multiplied by the ownership cost for the vehicle as this is spare capacity and is not subject to operational and labour costs. This result was added to the product of the total harvest volume (t) and the calculated haulage cost ($R.t^{-1}$) to derive the total cost associated with owning and operating the required number of each vehicle type. This value was added to the construction and maintenance costs derived from the FastTrack model to determine the differential cost of each system for direct comparison over the stipulated CERP. In addition to this comparison, the effect of renting out the spare capacity of each system was also considered (Section 5.2). It should be noted that the calculations above are simplistic and a detailed discrete simulation model such as McDonald *et al.* (2008) should ideally be used to determine the number of vehicles required. This falls outside the scope of this project.

4.4 Sensitivity Analysis

Climatic variability results in varying annual yields. These differ further from field to field according to soil characteristics, ratoon number, field aspect and management approaches. With variability being expected it is critical to determine how fluctuations in certain inputs to the model will affect the routing from start point to the mill. It was the intention of this section to assess the sensitivity of the routing results to changes in key input variables. Three sensitivity analyses were performed. Firstly, FastTrack's route selection as a function of annual tonnage was considered. Route selection as a function of vehicle slope limitations was considered second. Thirdly, an additional analysis was conducted utilising the economic model to compare how changes in fuel price would affect total system costs. This was done by changing the fuel price in the economic model and plotting the result on a graph. The sensitivity analyses were conducted on one FastTrack routing solution to avoid unnecessary duplication.

4.4.1 Route selection as a function of annual tonnage

The volume of sugarcane produced is critical to the feasibility of the route selected. It was hypothesised that the greater the volume of sugarcane to be transported, the more direct the route linking the start point with the mill will be. The number of consignments required to haul each harvest volume depends on each vehicle's haulage capacity. The capital expenditure for each vehicle is divided by the set CERP and is further divided by the total number of consignments required per annum. As the annual haulage volume increases, so the capital expenditure payable per consignment decreases and operational expenses increase in proportion to the total system costs. Fuel expense is a significant operational cost and is the only one considered in FastTrack. It was assumed that this would have sufficient influence on the routing result. Although this section does not consider the financial implications of these expected fluctuations in yield, it does consider the stability of the route selected under a range of yields, both above and below the previously assumed average.

The range of total crop volumes assumed is displayed in Table 4.2 and, although it is perhaps unrealistic to expect a harvest to ever reach fifty percent above the average, it does provide consideration of a scenario where a larger area, below the start point, could be planted to sugarcane.

Table 4.2 Test-range of total tons of transported sugarcane used to test the sensitivity of FastTrack routing solutions

Variation (%)	0	+ 10	- 10	+ 25	- 25	+ 50	- 50
Range (tons)	70000	77000	63000	87500	52500	105000	35000

4.4.2 Route selection as a function of slope restrictions

The digital elevation model (DEM) was converted into a slope map in process F15 in Figure 3.1. Slopes were divided into default categories depending on the range of slope present in an area. These were organised into specific slope sets in process F16 in Figure 3.1 depending on the climbing ability of each vehicle configuration. Slopes above the set maximum per vehicle type, were ascribed incremental costs based on the additional construction costs required for cut and fill operations. This ensures that the maximum slope would not be exceeded by any route selected by the model. These costs are added in addition to the general construction costs, I9 in Figure 3.1, which cover a range of construction scenarios and average cut and fill volumes. The range of slopes input into FastTrack for the purpose of the sensitivity analysis is included in Table 4.3 and will be used with data from only one vehicle solution.

Table 4.3 The range of slopes used to assess the sensitivity of a selected route to changes in the vehicle's maximum achievable slope

Variation (%)	0	+ 10	- 10	+ 25	- 25	+ 50	- 50
Slope range (%)	7	7.7	6.3	8.8	5.3	10.5	3.5

Research results are reported and synthesised in Chapter 5.

5 DEMONSTRATION OF THE FASTTRACK MODEL: CASE STUDY RESULTS

5.1 Routing Results

Figure 5.1 illustrates the FastTrack output for both the tractor hilo and the interlink as described in the previous chapter. The result is a 9300 m route along national roads from the start point to the mill.

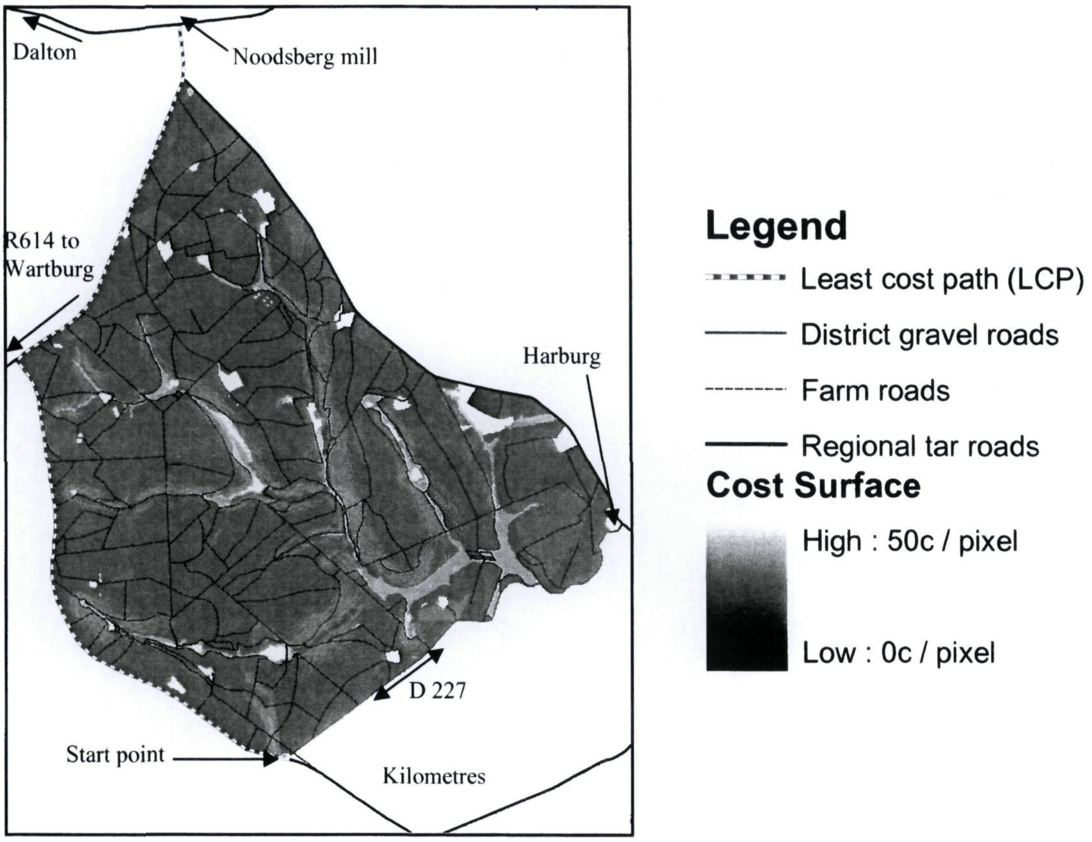


Figure 5.1 The LCP indicated in blue and white is the FastTrack route alignment for both the tractor hilo and the interlink on the tractor hilo cost surface map.

The solution presented in Figure 5.1 is acceptable as both vehicles can legally operate on national roads. With fuel costs being the only operating expense considered by FastTrack for the two vehicles, the volume of sugarcane, the terrain and distance to the mill, provided insufficient financial incentive to warrant a more direct path.

In contrast to the two previous solutions and with an assumed fine accounting for the illegality of the Bell2306$_{4x4}$ land train on national roads, FastTrack's solution only utilised a short 500 m section of national road directly before the mill, starting at Point A (Figure 5.2).

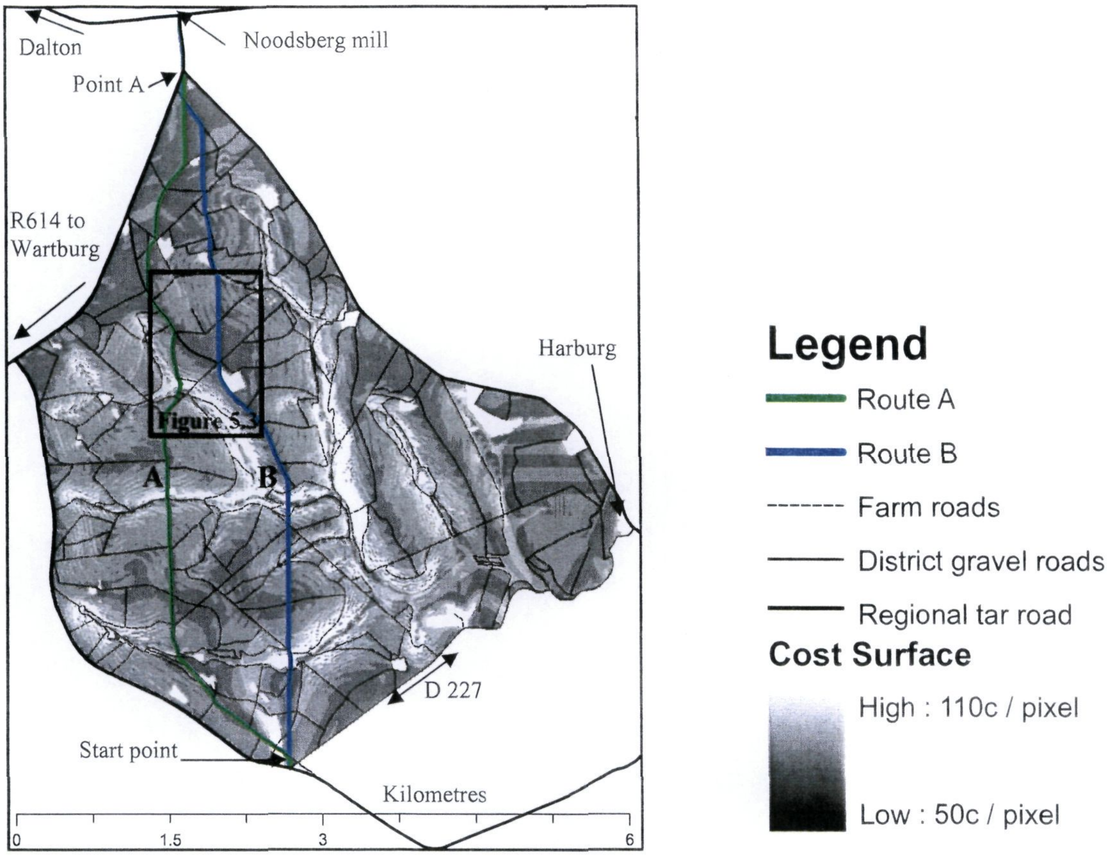


Figure 5.2 Two routing solutions for the Bell2306$_{4x4}$ land train system overlaid on the associated cost surface map.

Figure 5.2 illustrates two routes of differing length but equal cost. This cost includes the total road construction costs, maintenance thereof and the fuel costs accrued in hauling the set volume of 70 000 tons of sugarcane from the start point to the mill on a per trip basis as described in Section 3.1. This unique and unexpected result prompted vast testing and investigations into the workings of FastTrack (described in Section 3.4). FastTrack performed predictably under all of the tests carried out. The results for the land train were therefore accepted but a decision was required over the final selection of either Route A or Route B. This decision was made based on the consideration of various features associated with each alignment, such as route length, specific land use through which either alignment passes and the potential benefit which these offered to hauliers within Area A.

The first differentiating feature between the two routes is length. Route A is approximately 7983 m which is shorter than the 9300 m route suggested by the FastTrack model for the tractor hilo and the interlink, but is longer than Route B at approximately 7448 m. The cost of upgrading an existing road is in most circumstances less costly than constructing an entirely new one. The construction of Route A would result in 73 % of existing farm gravel roads being upgraded and utilised, as opposed to only 34 % for the more direct Route B. A shorter road has operational benefits in addition to reduced fuel usage, which were not considered in FastTrack. These include increased turn-around times and reduced long term road maintenance costs. Route B would, therefore, be selected if only route length were considered and if long term feasibility were considered more seriously.

If road safety and noise pollution were considered, then Route A may be selected. Route B passes close to a farm house with out-buildings, indicated in red in Figure 5.3. Depending on the particular land owner, this may be considered unacceptably close or pose a safety risk to residents of the farm house.

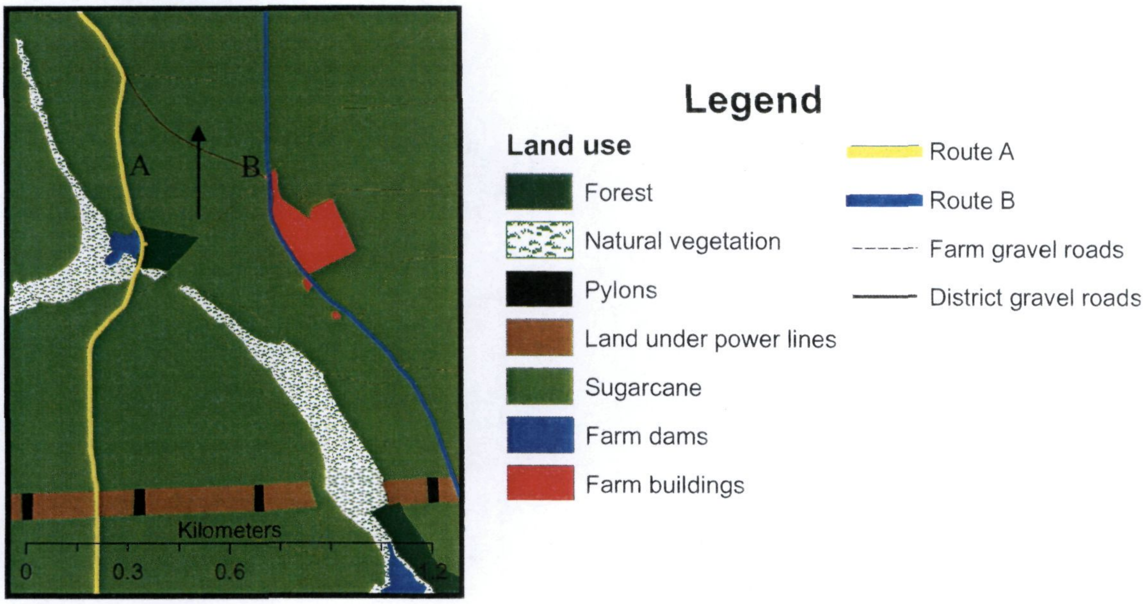


Figure 5.3 Land use map route comparison for a small subsection of the case study area (*cf.* Figure 5.2).

It is possible to add further constraints to the model, such as not allowing any new road to pass within 100 m of a wetland or farm building. These considerations need to be discussed within a study area to ensure that the best interests of all affected stakeholders are incorporated. For the purpose of this study it was decided that no further restrictions or cost surfaces would be imposed. It is recommended that Route A's path across the dam wall on an existing farm road be assessed in terms of the dam wall's suitability to handle heavy vehicle traffic. Similar to the route selection model presented by Sadek *et al.* (1999), the interpretation and final selection of a FastTrack solution is required to be made by the design team of each particular project.

As mentioned in Section 4.2.1, it is assumed that the haulage of harvested sugarcane within Area A would benefit from the addition of new transport routes through shorter haulage distances, quality road surfaces and improved turn-around times. The determination of the volume of sugarcane in close proximity to either of the two routes was utilised as another method of selecting the most cost effective route (Figure 5.4). A one kilometre buffer of land under sugarcane was added on both sides of each route. It was assumed that the buffered sugarcane would flow onto the proposed routes.

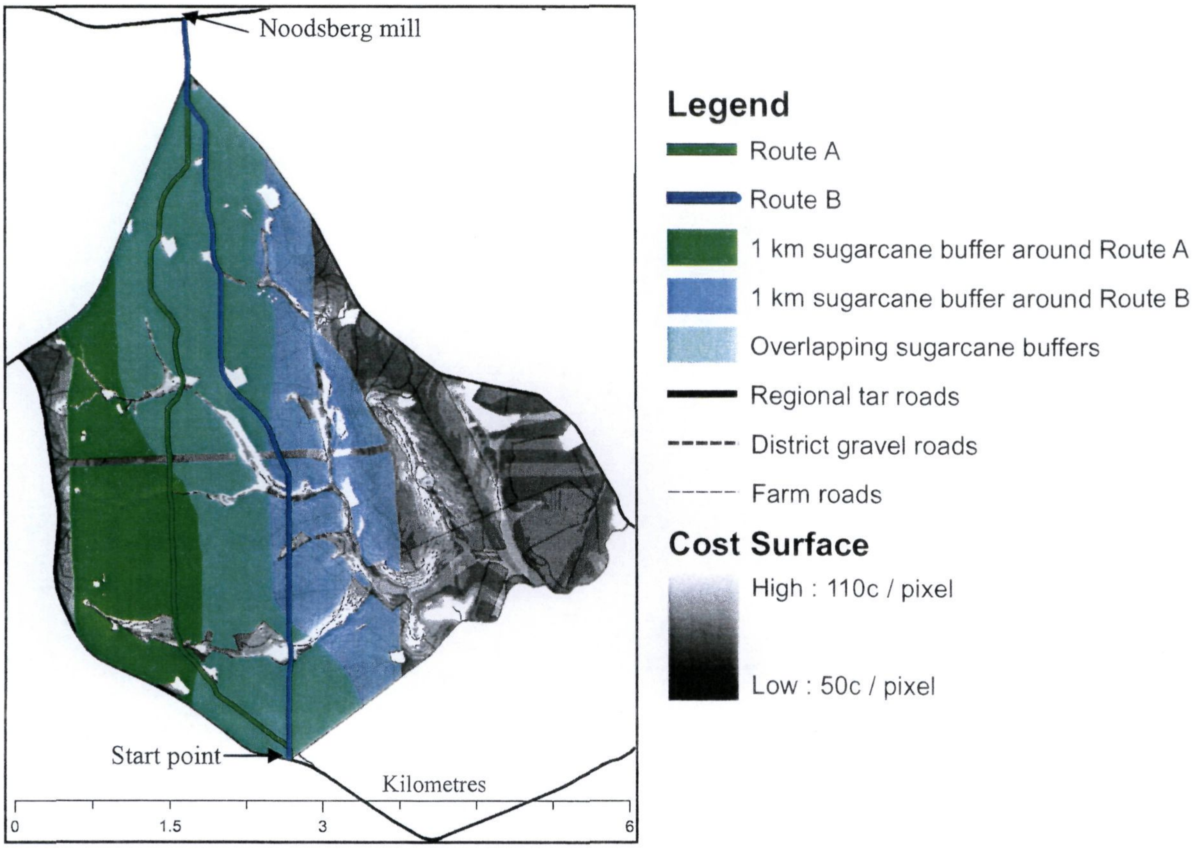


Figure 5.4 Buffers indicating the potential flow of sugarcane onto the proposed routes.

Route B passing nearest to the geometric centre of the study area, could potentially draw a volume of 41 200 tons of sugarcane annually, while Route A has a potential of 40 160 tons. This difference is not significant, however, much of the sugarcane assumed to flow onto Route A (indicated by the green buffer in Figure 5.4) borders national roads or is closer to a national road than to Route A. This sugarcane could be transported along the national roads using tractor hilos, therefore, reducing the volume which was assumed to flow onto Route A. Route B has the potential to transport a greater volume of the sugarcane in Area A than Route A and was thus preferred.

It was assumed that, despite land trains not being permitted to operate on national roads, an agreement could be reached between the land train operators and the relevant roads authority for the use of the 500 m stretch of the R614 between Point A and the mill (Figure 5.2). The assumption was based on the benefits which either of the proposed land train roads would offer to the regional roads authority. These include reduced traffic congestion and road maintenance costs on approximately 8700 m of national road. Hauliers could provide safety measures to improve road safety in return for the use of the 500 m stretch of road, including officials, road markings and appropriate signage. As an alternative it could be agreed upon to grade the road reserve adjacent to the national road on this short stretch as a continuation of either Route A or B. In this case, special measures would still be required when crossing over national roads as is necessary directly before the mill entrance.

Considering route length and sugarcane supply volumes within the study area, while disregarding the need for a buffer area around farmsteads and wetlands, Route B seems like the desired route selection. Route A was therefore not considered in the economic and sensitivity analyses which follow.

5.2 Economic Analysis Results

An economic analysis was conducted as described in Section 4.3 which enabled the FastTrack solutions for the three vehicles to be directly compared in terms of the differential system costs. In this way the optimum vehicle and infrastructural solution could be identified for the particular case study. Table 5.1 is a summary of the results with the final cost being expressed in terms of the cost in Rands to haul a ton of sugarcane from the start point to the mill. This includes all infrastructural and vehicle repayment concerns as detailed in Section 4.3.

Table 5.1 A summary of total system costs assembled to directly compare the three FastTrack solutions

	Bell 1866 AF	**Bell 2306D$_{4x4}$**	**M-B Actros 3350/33S**
Total road construction cost (R)	0.00	1725340.00	0.00
Total road maintenance cost (R)	0.00	593405.00	0.00
Ownership cost (R.h^{-1})	166.38	366.44	200.97
Operational cost (R.h^{-1})	221.65	425.15	578.69
Labour costs (R.h^{-1})	13.92	13.92	13.92
Number of vehicles required	6	3	3
Annual spare capacity (tons)	2587	16184	848
Total system cost over 5 years (R)	21172405	21984302	21406587
Effective cost (R/ton)	60.49	62.81	61.16
Cost if spare capacity is utilised (R/ton)	59.58	57.50	60.98

The effective cost per ton (Table 5.1) indicates that the three systems return fairly similar costs, with a difference of only R 2.32 between the land train and the tractor hilo which are the least and most cost effective options respectively. However, after considering the number of vehicles required to haul the set crop volume within the limited milling season length and the spare capacity available to each, an opportunity to reduce system costs was identified. This was based on the assumption that the spare capacity available to each vehicle, after the set volume had been delivered, could be rented to hauliers within the surrounding areas. The rent set for each vehicle was conservatively assumed to equal the hourly ownership cost for each vehicle type (Table 5.1). In the land train case there is a significantly large spare capacity of 16 184 tons which could be utilised to service Area A, where 41 200 tons of sugarcane within one kilometre of the proposed Route B exist. If the spare capacity was rented as described and the generated revenue was used to repay debts then the land train system is the most cost effective option with a difference of R 3.48 between it and the interlink system (Table 5.1).

It should be emphasised that the results were based on a five year capital expenditure repayment period (CERP). Savings generated utilising the land train system are, thus, expected to be more pronounced from year six onwards as road construction costs would be replaced with resurfacing costs, which, due to the assumed preventative maintenance plan (*cf.* Section 4.2.2), are expected to be reduced.

Under the current described conditions, haulage by means of a road train system, on the proposed Route B, is the most cost effective option.

5.3 Sensitivity Analysis

Only Route B for the land train system was considered in the sensitivity analysis due to its' significance in being the only result, bar Route A, that was not aligned exclusively along national roads. In addition, the majority of Route B (76 %) consisted of new road construction. It was therefore the aim of this section to determine how sensitive Route B was to changes in key input variables and in so doing to assess the sensitivity of FastTrack output in general. Further to this the effect of fuel price increases on operational costs are also considered.

The first variable to be manipulated in the analysis was the annual haulage volume of sugarcane according to input data from Table 4.2. Routes A and B (*cf.* Figure 5.2) were again output from FastTrack but were only simultaneously produced for the original crop volume of 70 000 tons of sugarcane (Figure 5.5).

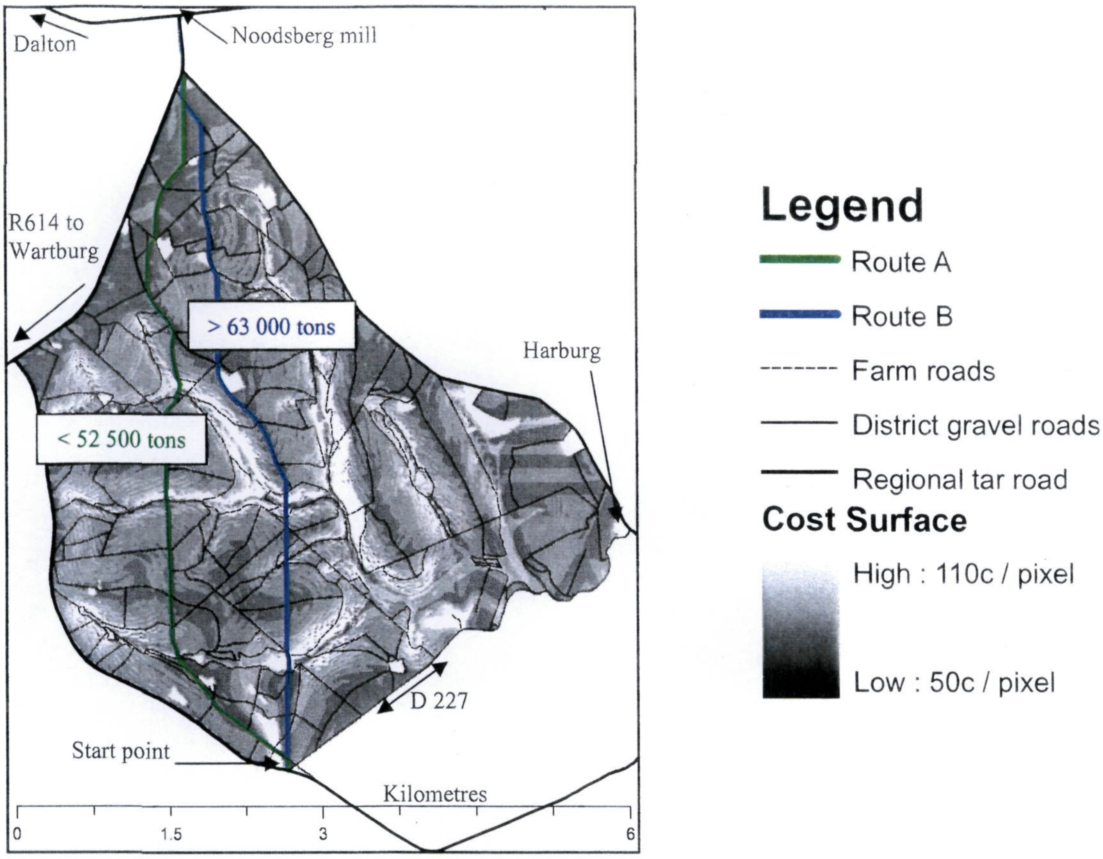


Figure 5.5 Land train routes selected according to annual haulage volume.

A threshold volume of sugarcane to be transported exists in-between 52 500 tons and 63 000 tons per annum. Below this value it was deemed more cost effective to make use of Route A, which, as described in Section 5.1, is slightly longer but makes use of 73 % of existing roads en route to the mill. Above the threshold volume, the more direct Route B was selected. This outcome demonstrates that, as operational expenses increase due to increases in crop volume, operational expenses eventually outweigh capital expenditure. The route that minimises operational expenses, *i.e.* the more direct route, which in this case is Route B, is consequently selected.

The second input variable adjusted for the sensitivity analysis was the slope climbing ability of the Bell $2306D_{4x4}$. After running the model with the slopes indicated in Table 4.3, a few variations to the original Routes A and B were determined (*cf.* Figure 5.2). Interestingly Route B was selected by FastTrack for slopes 5.25 %, 6.3 % and 7.7 %. At slopes 8.75 % and 10.5 %, which represent a 25 % and 50 % slope climbing improvement for the land train, respectively, Route C was produced (Figure 5.6). Route C varies only slightly from the original Routes A and B combined (*cf.* Figure 5.2) showing the robustness of the original FastTrack Solution (*cf.* Chapter 5.1).

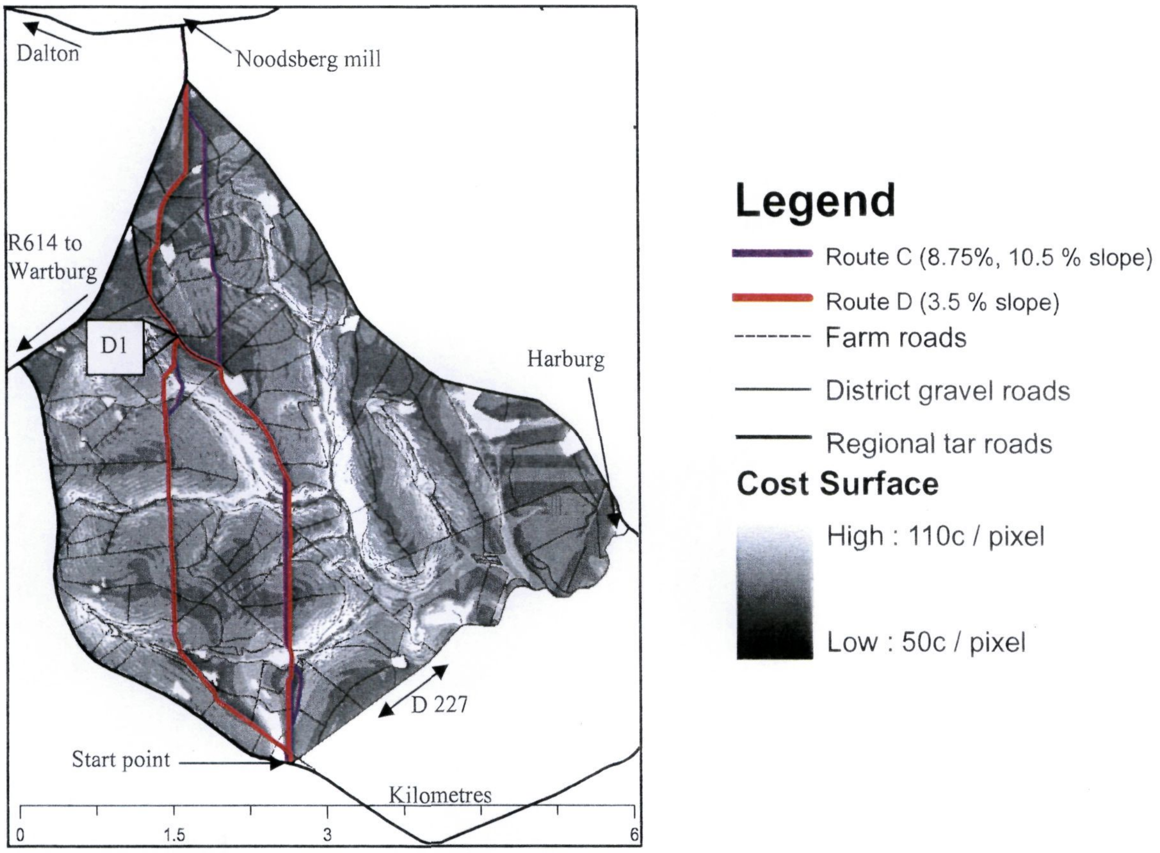


Figure 5.6 Land train routes selected according to vehicle slope limitations.

Route D is the outcome if the Bell $2306D_{4x4}$ was limited to climbing slopes of 3.5 % or less. This represents a 50 % restriction on the actual limitation decided upon in Section 4.2.3. Route D consists of two routes which separate initially and later rejoin at Point D1 (Figure 5.6). Following this, the alignment of Route A (*cf.* Figure 5.2) is deemed the most cost effective under the conditions and followed toward the mill yard. The two portions of Route D differ in length by approximately 200 m but are equal in cost according to FastTrack. If the land train were limited to slopes of 3.5 % or less, then a decision between the two branches could be made based on the potential benefit to Area A (*cf.* Figure 4.2) while considering any wetland and dam wall crossings and each routes proximity to farm buildings and worker compounds.

From the two sensitivity analyses carried out it is noted that the model results appear to be more sensitive to changes in slope than to changes in annual tonnage. This is affected by the geography of the area and a different result should be expected with each new study. The results however emphasized the stability of Route B, affirming its selection and demonstrating the robustness of FastTrack by not producing inexplicable anomalies.

After considering the sensitivity of FastTrack output to changes in input variables it was decided to investigate the affects that increasing fuel prices would have on the transport system costs as reviewed in the economic analysis (*cf.* Section 4.3 and Section 5.2). The resulting graph (Figure 5.7) illustrates that as the fuel price increases, the difference in system cost between the land train system and the other two systems also increases.

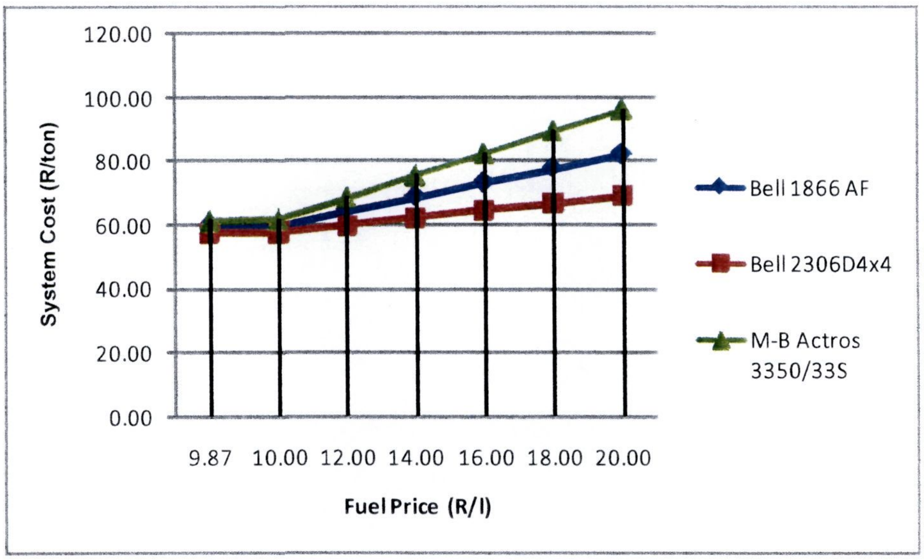


Figure 5.7 The system cost for each solution increases at a different yet constant rate as the fuel price increases.

The land train with its six trailers, road construction costs and maintenance expenses require the greatest capital investment. However, as the fuel price increases so the operational expenses increase and become more significant than the capital expenditure costs. The system with the greatest operational efficiency is therefore rendered the most cost effective option as well. With the current trends of increasing fuel prices, consideration of this on the system selection process is essential.

The sensitivity analysis has shown that FastTrack responded predictably under a range of input variables. The decision to select Route B over Route A in Section 5.1 was strengthened by the results of the sensitivity analysis as Route B was repeatedly plotted for data both above and below the values initialled input into the study.

5.4 Conclusions

FastTrack produced three infrastructural solutions for the vehicles modelled according to a variety of the input layers. The interlink and tractor hilo solutions followed existing roads en route to the mill while the land train alignment followed a more direct path on a proposed new road.

Results from the economic analysis showed that under current conditions the three vehicles modelled in FastTrack return fairly similar system costs within the stipulated CERP with the land train system offering a marginal cost advantage. Considering a second five year period where construction costs for the land train system are expected to drop, in conjunction with potential fuel price increases, the construction of Route B and the use of land trains thereon is expected to yield significant savings.

The sensitivity analyses confirmed the decision to select Route B and demonstrated the versatility and robust nature of FastTrack. Results indicated that for the particular study area FastTrack results are more sensitive to changes in vehicle slope limitations than changes in the total volume of sugarcane to be transported.

6 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

6.1 Conclusions

It is evident from the literature that infrastructure planning using GIS is superior to traditional methods. Although excellent at rapidly identifying the most efficient route based on any number of criteria, GIS infrastructure planning models can not yet produce full civil designs. Further to this the interpretation of model results often requires consideration of area specific social issues including public safety, relocation and political concerns which cannot be modelled easily. Complex algorithms identifying the least cost path operate within a GIS platform continue to evolve and adapt to suit new applications. As efficient as these models may be, the accuracy of the outcome depends on the precision of the input data.

Model development was aimed at creating a tool to assist in reducing costs in the transport sector of the sugar supply chain which contributes significantly to the total production costs of the industry. It was hypothesised that a GIS based infrastructure planning model could achieve this by identifying optimum routing solutions, per vehicle configuration, from depot to mill. The FastTrack model was therefore created and considers many input variables such as terrain, land use, distance, total crop volume and vehicle payloads in identifying the most cost effective route. An extensive verification process confirmed the functionality of the model. FastTrack proved an effective and valuable infrastructure planning tool by having the capacity to consider a wide range of attributes over a relatively large area and sufficiently propose suitable haulage routes under different assumptions.

A case study was conducted to demonstrate the capabilities of FastTrack. An area with a range of land uses and slopes, containing a network of farm infrastructure, and bordered by national roads and near the Noodsberg sugar mill in KwaZulu-Natal, was selected for this purpose. Data was collected for three different vehicle configurations, namely the Bell 1866 AF tractor hilo, the Bell 2306D_{4x4} land train and the Mercedes-Benz Actros 3350/33S interlink, varying in capacity and potential speed among other attributes. Despite the Euclidean distance being almost 20 % shorter in length than the route currently utilised by haulage vehicles from the selected start point, only the proposed alignment for the land train offered a viable alternative to travelling on existing national roads. An economic analysis on the results for the three vehicles identified that under current conditions the land train system, including the construction and maintenance of new road infrastructure, was the most cost effective transport solution. A variation of the economic analysis identified an increasing need for efficient transport systems as fuel prices increase. This strengthens the case for introducing land trains into the study area, as does the assumption that the cost savings derived from the land train system would increase during a second five year period as the proposed road would have been repaid.

A sensitivity analysis conducted on the proposed land train alignment highlighted the robustness of the FastTrack model by generating predictable results. It can be concluded therefore that GIS based infrastructure planning models, such as FastTrack, can indeed assist in reducing sugarcane haulage costs by identifying vehicle specific least-cost haulage routes.

6.2 Recommendations for Future Research

The information gathered during the case study was sourced from industry experts and researchers, including many industry guided assumptions. It is, however, proposed that several aspects of the FastTrack model can be expanded to include greater detail with the intention of increasing the thoroughness of future infrastructure planning studies. Recommendations for future research are listed below, *viz.*

- Currently the FastTrack model is able to plot the most efficient haulage route for any vehicle modelled based on a number of input variables including the performance capabilities of the selected vehicle. There is, however, no feedback facility which would enable FastTrack to propose an alignment based on a combination of vehicle types which may already be available to a haulier. This would be a major addition and would require the remodelling of many aspects of FastTrack to include several loops and iterations.

- The conversion of the road reserve next to a national road into a suitable gravel road for bulk agricultural haulage was not considered. Potential benefits of utilising this road reserve include reduced construction costs due to prior preparation of the road shoulder and zero expropriation costs. National road maintenance costs are also reduced due to the decrease in heavy vehicle traffic. If this were agreed upon by the regional roads authority then a buffer could be included on either side of the national roads in the study area. The buffer would be incorporated into the land use layer of FastTrack and would contain the relevant construction, expropriation and maintenance cost information.

- It is recommended that a function which correlates vehicle maintenance cost to road surface type be added to FastTrack. Data were gathered for each vehicle type in the case study based on conditions that it was likely to experience. By differentiating between vehicle maintenance costs according to road surface, a greater level of accuracy will added to FastTrack.

- It was deemed out of project scope to consider loading and infield operations. Adding a module to consider these and the costs involved with double handling, would broaden the scope of FastTrack.

- The model was constructed and operates within ArcGIS 9.2. It is recommended that the model be constructed in other GIS software packages which perhaps use different least cost algorithms. This would either confirm the results already obtained or offer an alternative to users. This would be of particular use if it were found that one algorithm performed better on a certain terrain type than another. Further to this, linking FastTrack to civil packages could assist in determining accurate cut and fill estimations while including soil specific costs would improve construction cost estimations.

- It is recommended that an environmental impact assessment (EIA) be conducted on all new road alignments proposed by FastTrack.

- Many of the system costs considered in the economic analysis such as ownership and operational costs could be included as broad cost surfaces within FastTrack. This would remove the need to utilise economic analyses to compare and quantify FastTrack results.

- The model is currently not user friendly. Programming is required to develop an input window where maps and excel tables can be added and where the model can be run at the click of a button. The same applies to developing an easily understood output showing the breakdown of costs for each solution. This would enable FastTrack to efficiently consider numerous transport combinations and would allow for easy comparisons between solutions.

- Off loading at the mill will need to change to accommodate a land train and to avoid delays to other vehicles. The cost of these changes also needs to be considered in a whole system change analysis.

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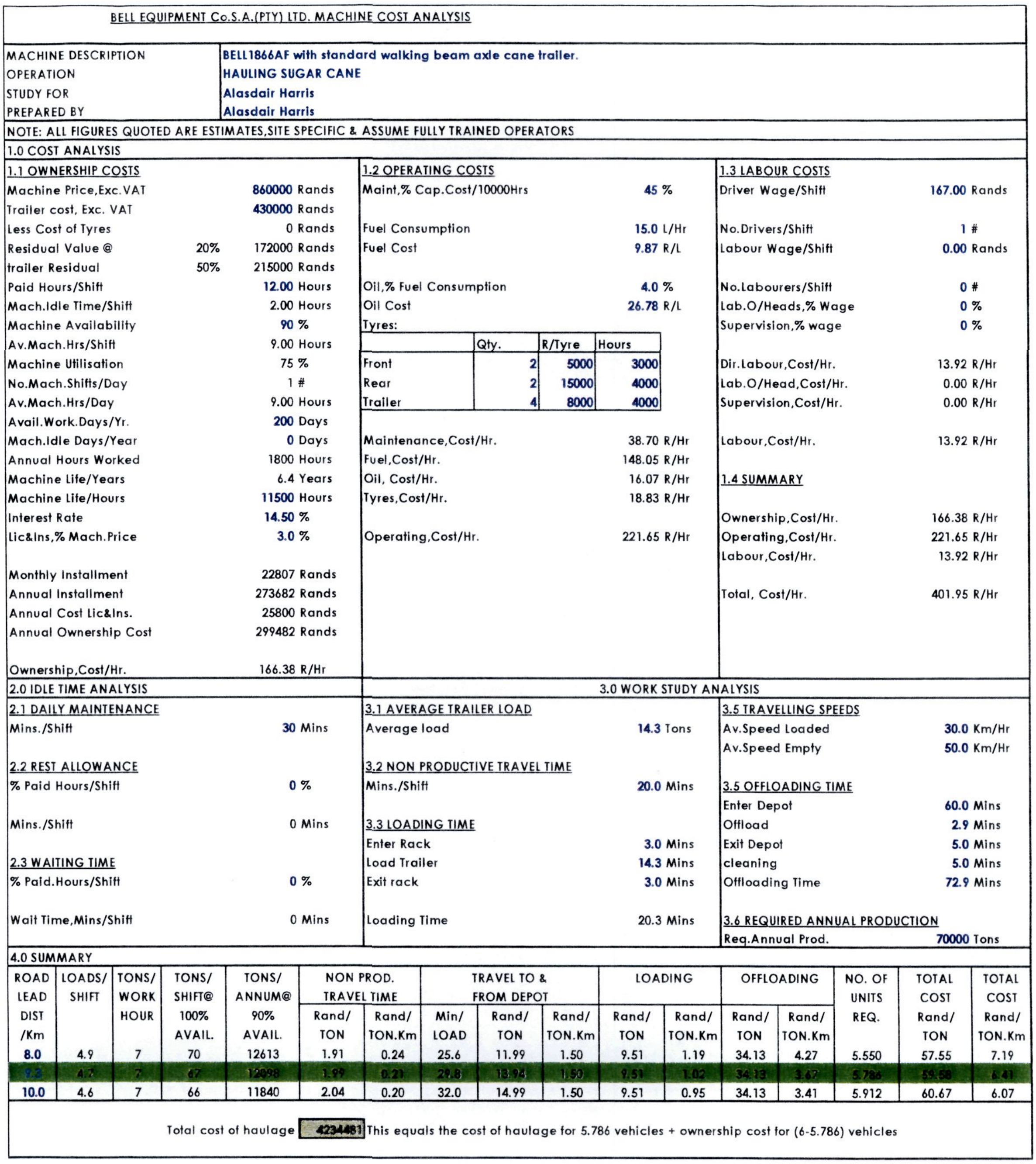
8 APPENDICES

Appendix A1. Summary of Model Inputs

	Vehicle Type (R/pixel)*		
Input	**1866 AF**	**2306 D**	**Actros 3350**
Fuel	0.048	0.062	0.052
Construction			
District tar	0.000	0.000	0.000
District gravel	0.082	0.326	0.183
Farm gravel	0.102	0.407	0.229
Everywhere else	0.123	0.489	0.274
Slope adjustment			
R50000 extra	0.020	0.081	0.046
R100000 extra	0.041	0.163	0.091
R200000 extra	0.082	0.326	0.183
R1000000 extra	0.409	1.629	0.914
Maintenance			
District tar	0.015	0.611	0.034
District gravel	0.041	0.163	0.091
Farm gravel	0.041	0.163	0.091
Everywhere else	0.041	0.163	0.091
Landuse	**Expropriation costs**		
Sugarcane	0.012	0.049	0.027
Forest (plantation)	0.009	0.037	0.021
Farm buildings	0.817	3.257	1.829
Dams	0.817	3.257	1.829
Riparian zones	0.082	0.326	0.183
Pylons	1.226	4.886	2.743
Land under pylons	0.012	0.049	0.027
District tar	0.000	0.000	0.000
District gravel	0.000	0.000	0.000
Farm gravel	0.000	0.000	0.000

*R/pixel/consignment based on the carrying capacity of each vehicle and the volume of sugarcane to be transported each season to ensure repayment of capital expenditure within a period of five years as discussed in Sections 4.3 and 5.2.

Appendix B1. Bell Equipment (PTY) LTD Costing Model for the Bell 1866AF



BELL EQUIPMENT Co.S.A.(PTY) LTD. MACHINE COST ANALYSIS

MACHINE DESCRIPTION	**BELL1866AF with standard walking beam axle cane trailer.**
OPERATION	**HAULING SUGAR CANE**
STUDY FOR	**Alasdair Harris**
PREPARED BY	**Alasdair Harris**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.0 COST ANALYSIS

1.1 OWNERSHIP COSTS

Machine Price,Exc.VAT		**860000**	Rands
Trailer cost, Exc. VAT		**430000**	Rands
Less Cost of Tyres		0	Rands
Residual Value @	20%	172000	Rands
trailer Residual	50%	215000	Rands
Paid Hours/Shift		**12.00**	Hours
Mach.Idle Time/Shift		2.00	Hours
Machine Availability		**90**	%
Av.Mach.Hrs/Shift		9.00	Hours
Machine Utilisation		75	%
No.Mach.Shifts/Day		1	#
Av.Mach.Hrs/Day		9.00	Hours
Avail.Work.Days/Yr.		**200**	Days
Mach.Idle Days/Year		**0**	Days
Annual Hours Worked		1800	Hours
Machine Life/Years		6.4	Years
Machine Life/Hours		**11500**	Hours
Interest Rate		**14.50**	%
Lic&Ins,% Mach.Price		**3.0**	%
Monthly Installment		22807	Rands
Annual Installment		273682	Rands
Annual Cost Lic&Ins.		25800	Rands
Annual Ownership Cost		299482	Rands
Ownership,Cost/Hr.		166.38	R/Hr

1.2 OPERATING COSTS

Maint,% Cap.Cost/10000Hrs	**45**	%
Fuel Consumption	**15.0**	L/Hr
Fuel Cost	**9.87**	R/L
Oil,% Fuel Consumption	**4.0**	%
Oil Cost	**26.78**	R/L

Tyres:

	Qty.	R/Tyre	Hours
Front	**2**	**5000**	**3000**
Rear	**2**	**15000**	**4000**
Trailer	**4**	**8000**	**4000**

Maintenance,Cost/Hr.	38.70	R/Hr
Fuel,Cost/Hr.	148.05	R/Hr
Oil, Cost/Hr.	16.07	R/Hr
Tyres,Cost/Hr.	18.83	R/Hr
Operating,Cost/Hr.	221.65	R/Hr

1.3 LABOUR COSTS

Driver Wage/Shift	**167.00**	Rands
No.Drivers/Shift	**1**	#
Labour Wage/Shift	**0.00**	Rands
No.Labourers/Shift	**0**	#
Lab.O/Heads,% Wage	**0**	%
Supervision,% wage	**0**	%
Dir.Labour,Cost/Hr.	13.92	R/Hr
Lab.O/Head,Cost/Hr.	0.00	R/Hr
Supervision,Cost/Hr.	0.00	R/Hr
Labour,Cost/Hr.	13.92	R/Hr

1.4 SUMMARY

Ownership,Cost/Hr.	166.38	R/Hr
Operating,Cost/Hr.	221.65	R/Hr
Labour,Cost/Hr.	13.92	R/Hr
Total, Cost/Hr.	401.95	R/Hr

2.0 IDLE TIME ANALYSIS

2.1 DAILY MAINTENANCE

Mins./Shift	**30**	Mins

2.2 REST ALLOWANCE

% Paid Hours/Shift	**0**	%
Mins./Shift	0	Mins

2.3 WAITING TIME

% Paid.Hours/Shift	**0**	%
Wait Time,Mins/Shift	0	Mins

3.0 WORK STUDY ANALYSIS

3.1 AVERAGE TRAILER LOAD

Average load	**14.3**	Tons

3.2 NON PRODUCTIVE TRAVEL TIME

Mins./Shift	**20.0**	Mins

3.3 LOADING TIME

Enter Rack	**3.0**	Mins
Load Trailer	**14.3**	Mins
Exit rack	**3.0**	Mins
Loading Time	20.3	Mins

3.5 TRAVELLING SPEEDS

Av.Speed Loaded	**30.0**	Km/Hr
Av.Speed Empty	**50.0**	Km/Hr

3.5 OFFLOADING TIME

Enter Depot	**60.0**	Mins
Offload	**2.9**	Mins
Exit Depot	**5.0**	Mins
cleaning	**5.0**	Mins
Offloading Time	**72.9**	Mins

3.6 REQUIRED ANNUAL PRODUCTION

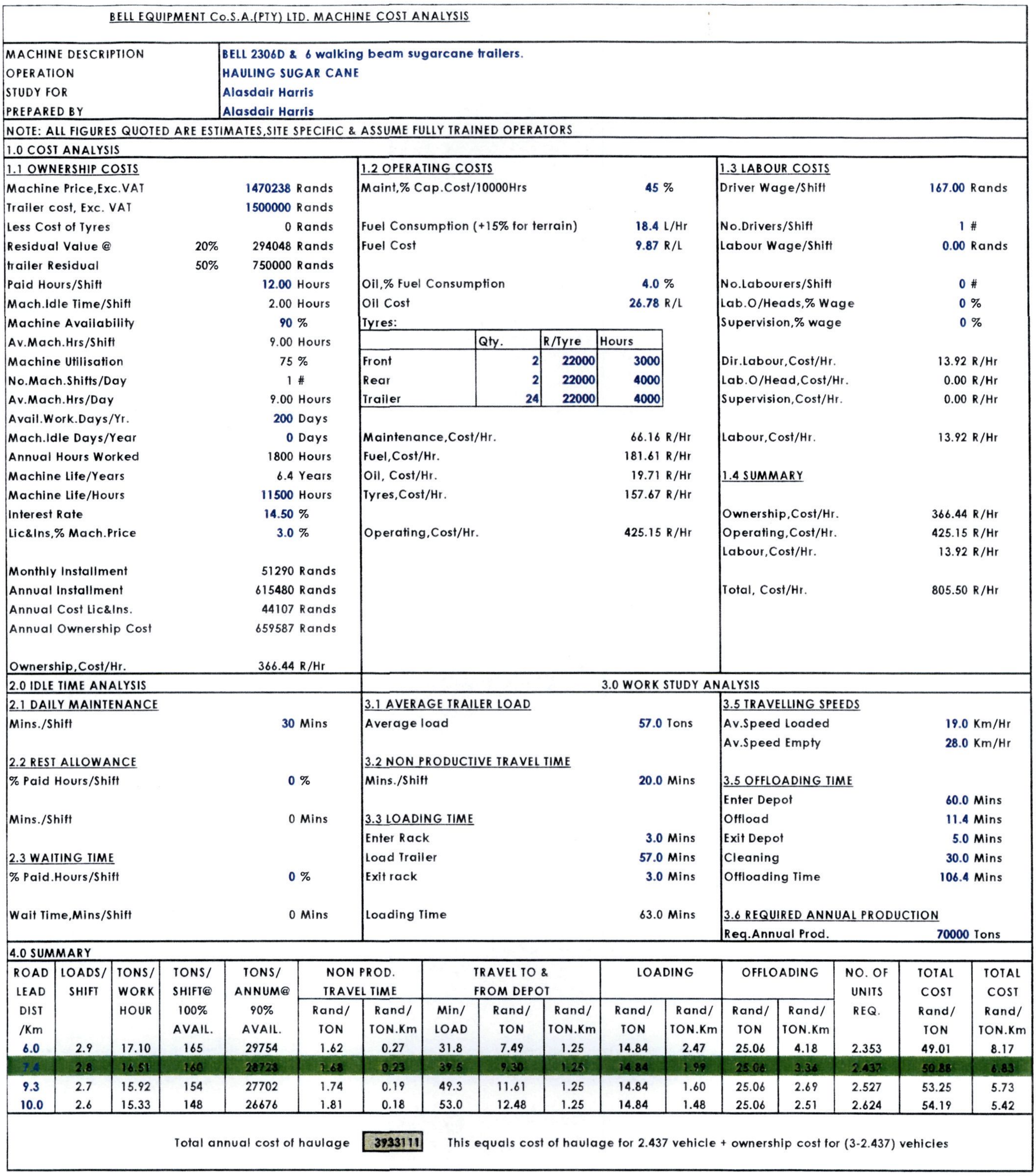
Req.Annual Prod.	**70000**	Tons

4.0 SUMMARY

ROAD LEAD DIST /Km	LOADS/ SHIFT	TONS/ WORK HOUR	TONS/ SHIFT@ 100% AVAIL.	TONS/ ANNUM@ 90% AVAIL.	NON PROD. TRAVEL TIME		TRAVEL TO & FROM DEPOT			LOADING		OFFLOADING		NO. OF UNITS REQ.	TOTAL COST Rand/ TON	TOTAL COST Rand/ TON.Km
					Rand/ TON	Rand/ TON.Km	Min/ LOAD	Rand/ TON	Rand/ TON.Km	Rand/ TON	Rand/ TON.Km	Rand/ TON	Rand/ TON.Km			
8.0	4.9	7	70	12613	1.91	0.24	25.6	11.99	1.50	9.51	1.19	34.13	4.27	5.550	57.55	7.19
9.3	4.7	7	67	12098	1.99	0.21	29.8	13.94	1.50	9.51	1.02	34.13	3.67	5.786	59.58	6.41
10.0	4.6	7	66	11840	2.04	0.20	32.0	14.99	1.50	9.51	0.95	34.13	3.41	5.912	60.67	6.07

Total cost of haulage 4234481 This equals the cost of haulage for 5.786 vehicles + ownership cost for (6-5.786) vehicles

Appendix B2. Bell Equipment (PTY) LTD Costing Model for the Bell 2306D$_{4x4}$



BELL EQUIPMENT Co.S.A.(PTY) LTD. MACHINE COST ANALYSIS

MACHINE DESCRIPTION	BELL 2306D & 6 walking beam sugarcane trailers.
OPERATION	HAULING SUGAR CANE
STUDY FOR	Alasdair Harris
PREPARED BY	Alasdair Harris

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.0 COST ANALYSIS

1.1 OWNERSHIP COSTS

Machine Price,Exc.VAT		1470238	Rands
Trailer cost, Exc. VAT		1500000	Rands
Less Cost of Tyres		0	Rands
Residual Value @	20%	294048	Rands
trailer Residual	50%	750000	Rands
Paid Hours/Shift		12.00	Hours
Mach.Idle Time/Shift		2.00	Hours
Machine Availability		90	%
Av.Mach.Hrs/Shift		9.00	Hours
Machine Utilisation		75	%
No.Mach.Shifts/Day		1	#
Av.Mach.Hrs/Day		9.00	Hours
Avail.Work.Days/Yr.		200	Days
Mach.Idle Days/Year		0	Days
Annual Hours Worked		1800	Hours
Machine Life/Years		6.4	Years
Machine Life/Hours		11500	Hours
Interest Rate		14.50	%
Lic&Ins,% Mach.Price		3.0	%
Monthly Installment		51290	Rands
Annual Installment		615480	Rands
Annual Cost Lic&Ins.		44107	Rands
Annual Ownership Cost		659587	Rands
Ownership,Cost/Hr.		366.44	R/Hr

1.2 OPERATING COSTS

Maint,% Cap.Cost/10000Hrs	45	%
Fuel Consumption (+15% for terrain)	18.4	L/Hr
Fuel Cost	9.87	R/L
Oil,% Fuel Consumption	4.0	%
Oil Cost	26.78	R/L

Tyres:

	Qty.	R/Tyre	Hours
Front	2	22000	3000
Rear	2	22000	4000
Trailer	24	22000	4000

Maintenance,Cost/Hr.	66.16	R/Hr
Fuel,Cost/Hr.	181.61	R/Hr
Oil, Cost/Hr.	19.71	R/Hr
Tyres,Cost/Hr.	157.67	R/Hr
Operating,Cost/Hr.	425.15	R/Hr

1.3 LABOUR COSTS

Driver Wage/Shift	167.00	Rands
No.Drivers/Shift	1	#
Labour Wage/Shift	0.00	Rands
No.Labourers/Shift	0	#
Lab.O/Heads,% Wage	0	%
Supervision,% wage	0	%
Dir.Labour,Cost/Hr.	13.92	R/Hr
Lab.O/Head,Cost/Hr.	0.00	R/Hr
Supervision,Cost/Hr.	0.00	R/Hr
Labour,Cost/Hr.	13.92	R/Hr

1.4 SUMMARY

Ownership,Cost/Hr.	366.44	R/Hr
Operating,Cost/Hr.	425.15	R/Hr
Labour,Cost/Hr.	13.92	R/Hr
Total, Cost/Hr.	805.50	R/Hr

2.0 IDLE TIME ANALYSIS

2.1 DAILY MAINTENANCE		
Mins./Shift	30	Mins
2.2 REST ALLOWANCE		
% Paid Hours/Shift	0	%
Mins./Shift	0	Mins
2.3 WAITING TIME		
% Paid.Hours/Shift	0	%
Wait Time,Mins/Shift	0	Mins

3.0 WORK STUDY ANALYSIS

3.1 AVERAGE TRAILER LOAD		
Average load	57.0	Tons
3.2 NON PRODUCTIVE TRAVEL TIME		
Mins./Shift	20.0	Mins
3.3 LOADING TIME		
Enter Rack	3.0	Mins
Load Trailer	57.0	Mins
Exit rack	3.0	Mins
Loading Time	63.0	Mins

3.5 TRAVELLING SPEEDS		
Av.Speed Loaded	19.0	Km/Hr
Av.Speed Empty	28.0	Km/Hr
3.5 OFFLOADING TIME		
Enter Depot	60.0	Mins
Offload	11.4	Mins
Exit Depot	5.0	Mins
Cleaning	30.0	Mins
Offloading Time	106.4	Mins
3.6 REQUIRED ANNUAL PRODUCTION		
Req.Annual Prod.	70000	Tons

4.0 SUMMARY

ROAD LEAD DIST /Km	LOADS/ SHIFT	TONS/ WORK HOUR	TONS/ SHIFT@ 100% AVAIL.	TONS/ ANNUM@ 90% AVAIL.	NON PROD. TRAVEL TIME		TRAVEL TO & FROM DEPOT			LOADING		OFFLOADING		NO. OF UNITS REQ.	TOTAL COST Rand/ TON	TOTAL COST Rand/ TON.Km
					Rand/ TON	Rand/ TON.Km	Min/ LOAD	Rand/ TON	Rand/ TON.Km	Rand/ TON	Rand/ TON.Km	Rand/ TON	Rand/ TON.Km			
6.0	2.9	17.10	165	29754	1.62	0.27	31.8	7.49	1.25	14.84	2.47	25.06	4.18	2.353	49.01	8.17
7.4	2.8	16.51	160	28723	1.68	0.23	39.5	9.30	1.25	14.84	1.99	25.06	3.36	2.437	50.88	6.83
9.3	2.7	15.92	154	27702	1.74	0.19	49.3	11.61	1.25	14.84	1.60	25.06	2.69	2.527	53.25	5.73
10.0	2.6	15.33	148	26676	1.81	0.18	53.0	12.48	1.25	14.84	1.48	25.06	2.51	2.624	54.19	5.42

Total annual cost of haulage 3933111 This equals cost of haulage for 2.437 vehicle + ownership cost for (3-2.437) vehicles

Appendix B3. Bell Equipment (PTY) LTD Costing Model for the Mercedes-Benz Actros 3350/33S

BELL EQUIPMENT Co.S.A.(PTY) LTD. MACHINE COST ANALYSIS

MACHINE DESCRIPTION	**BELL1866 & TANDEM TRAILERS.**
OPERATION	**HAULING SUGAR CANE**
STUDY FOR	**Alasdair Harris**
PREPARED BY	**Alasdair Harris**

NOTE: ALL FIGURES QUOTED ARE ESTIMATES,SITE SPECIFIC & ASSUME FULLY TRAINED OPERATORS

1.0 COST ANALYSIS

1.1 OWNERSHIP COSTS

Machine Price,Exc.VAT		999999	Rands
Trailer cost, Exc. VAT		570000	Rands
Less Cost of Tyres		0	Rands
Residual Value @	20%	200000	Rands
trailer Residual	50%	285000	Rands
Paid Hours/Shift		12.00	Hours
Mach.Idle Time/Shift		2.00	Hours
Machine Availability		90	%
Av.Mach.Hrs/Shift		9.00	Hours
Machine Utilisation		75	%
No.Mach.Shifts/Day		1	#
Av.Mach.Hrs/Day		9.00	Hours
Avail.Work.Days/Yr.		200	Days
Mach.Idle Days/Year		0	Days
Annual Hours Worked		1800	Hours
Machine Life/Years		6.4	Years
Machine Life/Hours		11500	Hours
Interest Rate		14.50	%
Lic&Ins,% Mach.Price		3.0	%
Monthly Installment		27645	Rands
Annual Installment		331743	Rands
Annual Cost Lic&Ins.		30000	Rands
Annual Ownership Cost		361743	Rands
Ownership,Cost/Hr.		200.97	R/Hr

1.2 OPERATING COSTS

Maint,% Cap.Cost/10000Hrs	45	%
Fuel Consumption	45.0	L/Hr
Fuel Cost	9.87	R/L
Oil,% Fuel Consumption	4.0	%
Oil Cost	26.78	R/L

Tyres:

	Qty.	R/Tyre	Hours
Front	2	6000	3000
Rear	8	6000	3000
Trailer	16	6000	4500

Maintenance,Cost/Hr.	45.00	R/Hr
Fuel,Cost/Hr.	444.15	R/Hr
Oil, Cost/Hr.	48.20	R/Hr
Tyres,Cost/Hr.	41.33	R/Hr
Operating,Cost/Hr.	578.69	R/Hr

1.3 LABOUR COSTS

Driver Wage/Shift	167.00	Rands
No.Drivers/Shift	1	#
Labour Wage/Shift	0.00	Rands
No.Labourers/Shift	0	#
Lab.O/Heads,% Wage	0	%
Supervision,% wage	0	%
Dir.Labour,Cost/Hr.	13.92	R/Hr
Lab.O/Head,Cost/Hr.	0.00	R/Hr
Supervision,Cost/Hr.	0.00	R/Hr
Labour,Cost/Hr.	13.92	R/Hr

1.4 SUMMARY

Ownership,Cost/Hr.	200.97	R/Hr
Operating,Cost/Hr.	578.69	R/Hr
Labour,Cost/Hr.	13.92	R/Hr
Total, Cost/Hr.	793.57	R/Hr

2.0 IDLE TIME ANALYSIS

2.1 DAILY MAINTENANCE

Mins./Shift	30	Mins

2.2 REST ALLOWANCE

% Paid Hours/Shift	0	%
Mins./Shift	0	Mins

2.3 WAITING TIME

% Paid.Hours/Shift	0	%
Wait Time,Mins/Shift	0	Mins

3.0 WORK STUDY ANALYSIS

3.1 AVERAGE TRAILER LOAD

Average load	32.0	Tons

3.2 NON PRODUCTIVE TRAVEL TIME

Mins./Shift	20.0	Mins

3.3 LOADING TIME

Enter Rack	3.0	Mins
Load Trailer	32.0	Mins
Exit rack	3.0	Mins
Loading Time	38.0	Mins

3.5 TRAVELLING SPEEDS

Av.Speed Loaded	40.0	Km/Hr
Av.Speed Empty	60.0	Km/Hr

3.5 OFFLOADING TIME

Enter Depot	60.0	Mins
Offload	6.4	Mins
Exit Depot	5.0	Mins
cleaning	10.0	Mins
Offloading Time	81.4	Mins

3.6 REQUIRED ANNUAL PRODUCTION

Req.Annual Prod.	70000	Tons

4.0 SUMMARY

ROAD LEAD DIST /Km	LOADS/ SHIFT	TONS/ WORK HOUR	TONS/ SHIFT@ 100% AVAIL.	TONS/ ANNUM@ 90% AVAIL.	NON PROD. TRAVEL TIME		TRAVEL TO & FROM DEPOT			LOADING		OFFLOADING		NO. OF UNITS REQ.	TOTAL COST Rand/ TON	TOTAL COST Rand/ TON.Km
					Rand/ TON	Rand/ TON.Km	Min/ LOAD	Rand/ TON	Rand/ TON.Km	Rand/ TON	Rand/ TON.Km	Rand/ TON	Rand/ TON.Km			
8.0	4.2	14	134	24192	1.97	0.25	20.0	8.27	1.03	15.71	1.96	33.64	4.21	2.894	59.58	7.45
9.3	4.1	14	131	23616	2.02	0.22	23.3	9.61	1.03	15.71	1.69	33.64	3.62	2.964	60.98	6.56
10.0	4.0	13	128	23040	2.07	0.21	25.0	10.33	1.03	15.71	1.57	33.64	3.36	3.038	61.75	6.17

Total cost of harvest **4281317** This equals the cost of haulage for 2.964 vehicle + ownership cost for (3-2.964) vehicles