

USING SHUTTLE RADAR TOPOGRAPHY MISSION (SRTM) DATA FOR GEOMETRIC DESIGN OF CONCEPTUAL RAILWAY ROUTE ALIGNMENTS

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ABSTRACT

The majority of new greenfield railway projects in Sub-Saharan Africa is driven by mining activity in the region and the transportation of these bulk commodities. The logistical solution to export/import bulk commodities to or from these new mines, is becoming increasingly complex with the key new resources moving further away from major port facilities.

Mining companies are often challenged in performing high level, first order studies on the logistical solution to validate the viability of the mine. The cost of the logistical solution (pit-to-port) usually plays a major role in determining the viability of the mine for the particular resource.

In conducting high level studies for a new railway in remote areas in Africa, the geometric designer is usually challenged with not having any topographical data, such as the 1:50 000 topography maps. This paper illustrates how Shuttle Radar Topography Mission (SRTM) satellite data can be used in a first order geometric design feasibility to establish a viable horizontal and vertical rail alignment with its associated infrastructure cost, such as earthworks, bridges, drainage, trackwork, etc. The horizontal and vertical alignment is then used to ascertain the haulage cost to the first order (for instance $\pm 30\%$ accurate) for the specific mine, considering the given tonnages and mine life cycle. SRTM satellite data can also be used very effectively to establish the best possible route alignment alternative, before a detailed study is conducted or instead of surveying all the possible route alignments.

1 INTRODUCTION

One of the major challenges for the mining industry currently in Africa, is to develop a reliable, logistical solution to export or import bulk commodities. Tonnages larger than 1 Mtpa (depending on the haulage distance) typically require a railway solution. The logistical solutions are also becoming increasingly complex with the key new resources moving further away from major port facilities.

The logistical solution often also controls the feasibility of the mine, and mining companies are often challenged in performing a quick, effective and accurate first order feasibility. If the cost of the logistical solution (pit-to-port) is not accurately depicted in the first order study (for instance $\pm 30\%$), it may lead to a false impression on the actual viability of the mine. The logistical chain should also be seen as an integrated solution from pit-to-port and almost acts as a "conveyor belt" from the mine into the ship (see Figure 1). All aspects of this logistical chain must be well integrated with no bottlenecks.

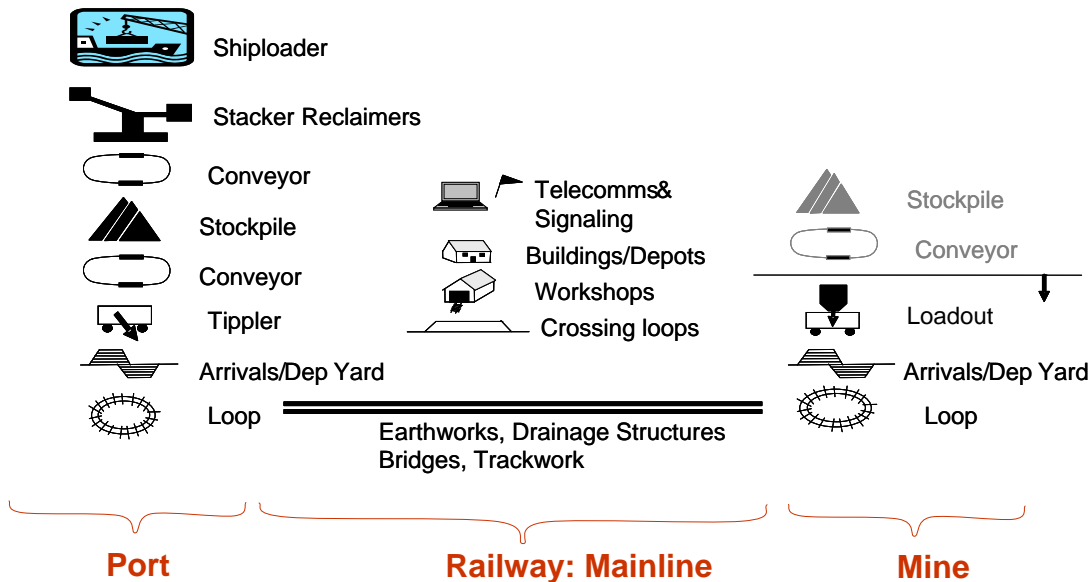


Figure 1: Integrated Logistical Chain from Pit-To-Port

The various typical development phases in a typical railway mining project are shown in Figure 2. This paper covers the development of Phase 1, which, as mentioned, plays a key role in determining the viability of the mine, considering the given tonnages and project life cycle.

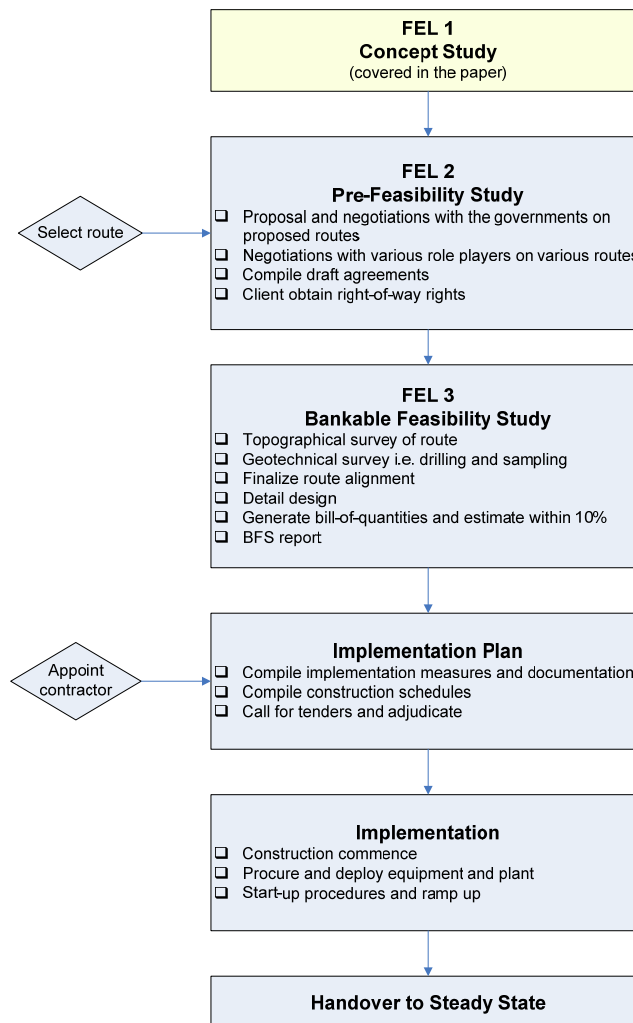


Figure 2: Typical Project Development Phases

In conducting these first order studies in remote areas in Africa, the geometric designer is usually challenged with not having any topographical data, such as the 1:50 000 topography maps. This paper illustrates how SRTM satellite data (Ref.1) can be used in a first order geometric design study to establish a viable horizontal and vertical rail alignment with its associated infrastructure cost such as earthworks, bridges, drainage, trackwork, etc. The horizontal and vertical alignment, with its associated infrastructure cost, is then used to ascertain the haulage cost for the specific mine considering the given tonnages and mine life cycle. SRTM satellite data can also be used very effectively to establish the alignment route alternative before a detailed study is conducted or instead of surveying all the route alignments.

This paper discusses the design principles as input into such a study, the methodology in establishing the route alignment, train dynamic modelling and the life cycle costing, and the comparison of the alternative alignments or options.

2 ESTABLISHING THE DESIGN PRINCIPLES

Before any high level greenfield railway line study can be conducted, the design criteria and principles must be fixed. The design criteria determine the design standards and affect the alignment standards applied to the project. Important design criteria to be considered before the project commences, include the following:

i. Design Traffic

The design traffic directly influences the rail standard to be applied. What type of commodities will be carried on the line, bulk, general container traffic, passengers etc.? In the case of bulk commodities like coal and iron ore, the volumes are the most significant aspect in determining the applied standard.

ii. Track Gauge

The gauge selection of a project is not necessarily straightforward. Railways in Africa are mostly of the narrow gauge variety (1 067 mm; 85%) and account for less than 7% of the world's railways by kilometres. One of the challenges facing Africa is how to adapt its rail infrastructure systems in order to respond to and integrate with the emerging trading systems (Ref. 2).

The dominant gauge in the world is 1 435 mm (> 60%). It is classified as Standard Gauge (SG) and has various advantages over narrow gauge. Stability is better and may permit higher speeds as well as higher and wider rolling stock. Sheer economy of scale provides advantages in the research, development and availability of rolling stock.

iii. Track Geometry

The macro track geometry determines the standards to be applied on the track alignment. Minimum horizontal curves as well as a minimum and maximum ruling grade must be specified for the alignment. These standards directly affect the amount of earthworks, tunnels and viaducts on the line and therefore directly impact the capital cost of the line. Horizontal and vertical design standards for railways are more stringent compared to, for example, a road, and the challenges to optimize the cost of a railway alignment is therefore greater compared to a road. For example, in mountainous terrain, a road can simply follow the terrain contours with sharp bends and steep grades in order to minimize earthworks quantities. This is not possible with a railway.

iv. Earthworks

The earthworks standards applied to the project directly impacts the project cost and is typically related to the track design axle load.

v. Track Superstructure Configuration

The track superstructure consists of the rails, sleepers, fasteners, and ballast. A classification of track superstructure for various axle loads and traffic volumes is shown in Figure 3.

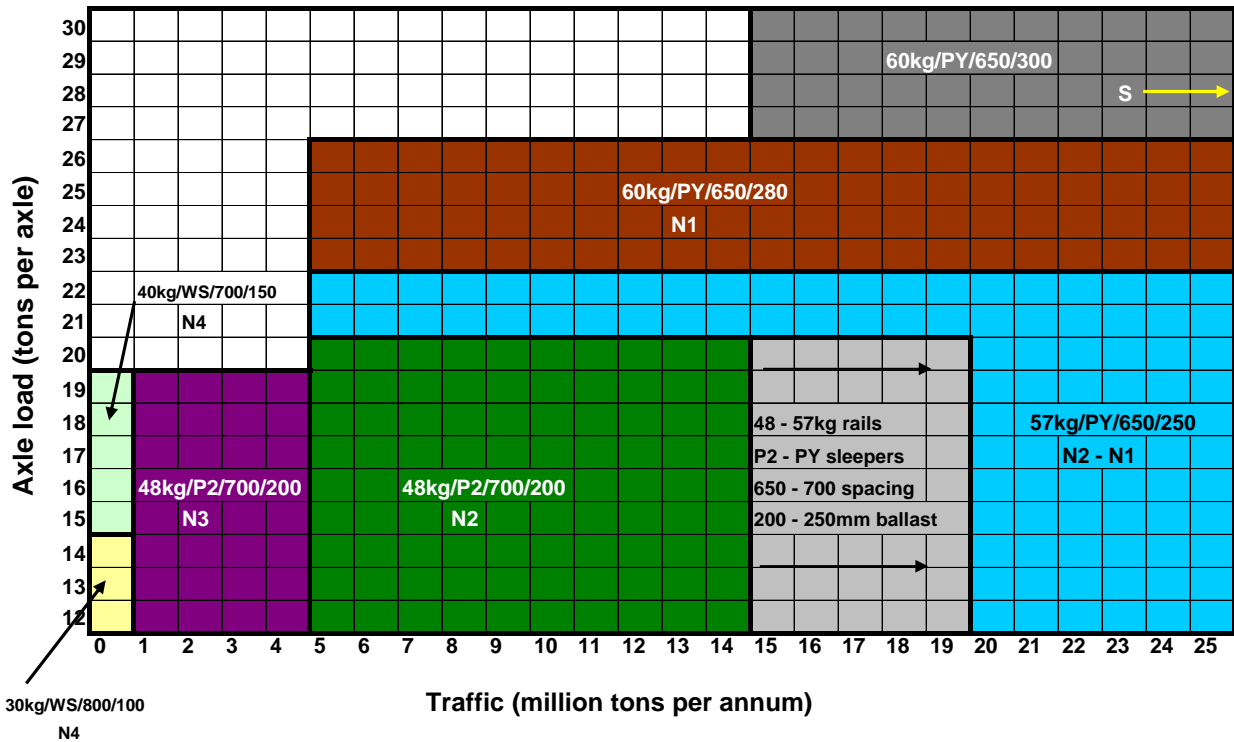


Figure 3: Classification of Track Superstructure for Axle Loads and Traffic Volumes (Ref. 4)

Design criteria that impact the rail alignment selection to a lesser extent include rolling stock standards, clearances, signalling and telecommunication, etc., and are not covered in this paper.

3 METHODOLOGY IN ESTABLISHING THE ROUTE ALIGNMENT

The design criteria (grade limitations, track lengths and minimum horizontal curves) will be used as the basis of the macro route selection. On a typical heavy haul line, a minimum horizontal radius of 1 000 m with a maximum ruling grade of 1:100 may be applicable.

Rail alignments are developed for each route corridor identified. The software programs that can be used for the route determination study include:

- Global Mapper;
- Google Earth;
- Map Source; and
- Alignment design software such as Inrail, Civil Designer, Civil 3D, etc.

Global Mapper and Google Earth are used for visual information on the area and first order location of the route, by using the SRTM 90 m Digital Elevation Data from the Consortium for Spatial Information (CGIAR-CSI) database (Ref. 3). Digital Terrain Models (DTMs) are created for the various first order routes from the data exported out of Global Mapper. The alignment design software is then used for the final design of the route.

Methods used to determine the routes are usually as follows:

- Use visual information including topographical information to determine possible routes.
- Export DTM strips in the specific LO bands to an ASCII file to form a platform for the geometric design.
- Generate contours using the Design Suite Software. Determine the optimum route for each alternative by analyzing the contours in order to achieve specified grade requirements. In problem areas, such as rolling topography and steep falls, software functions such as “generating grade contours”, determine possible routes by automatically searching for a route with a specific grade.

Alignments will be adjusted to try and follow existing infrastructure (railway lines, roads, transmission lines, farm boundaries, etc.) as far as possible, without resulting in unreasonable earthworks quantities. It is therefore important to note that the final alignments presented are not necessarily the most optimum alignments in terms of earthworks quantities and cost. Figure 4 and Figure 5 show a plan and 3D view of a typical alignment in the dataset.

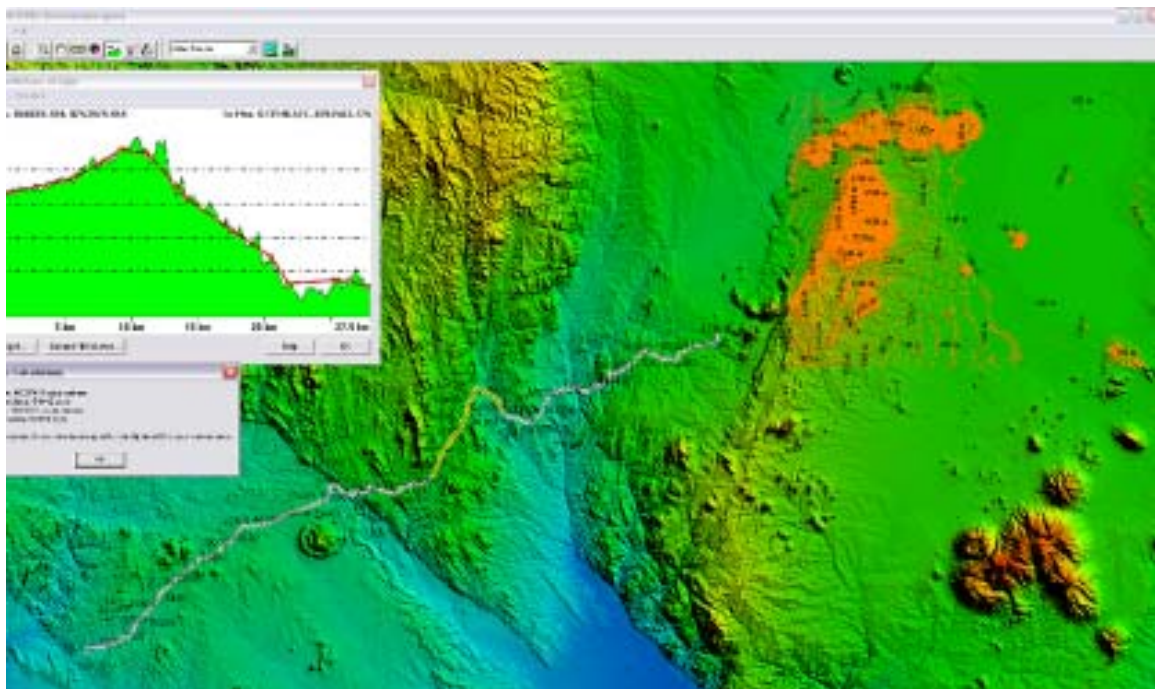


Figure 4: Plan View of Alignment

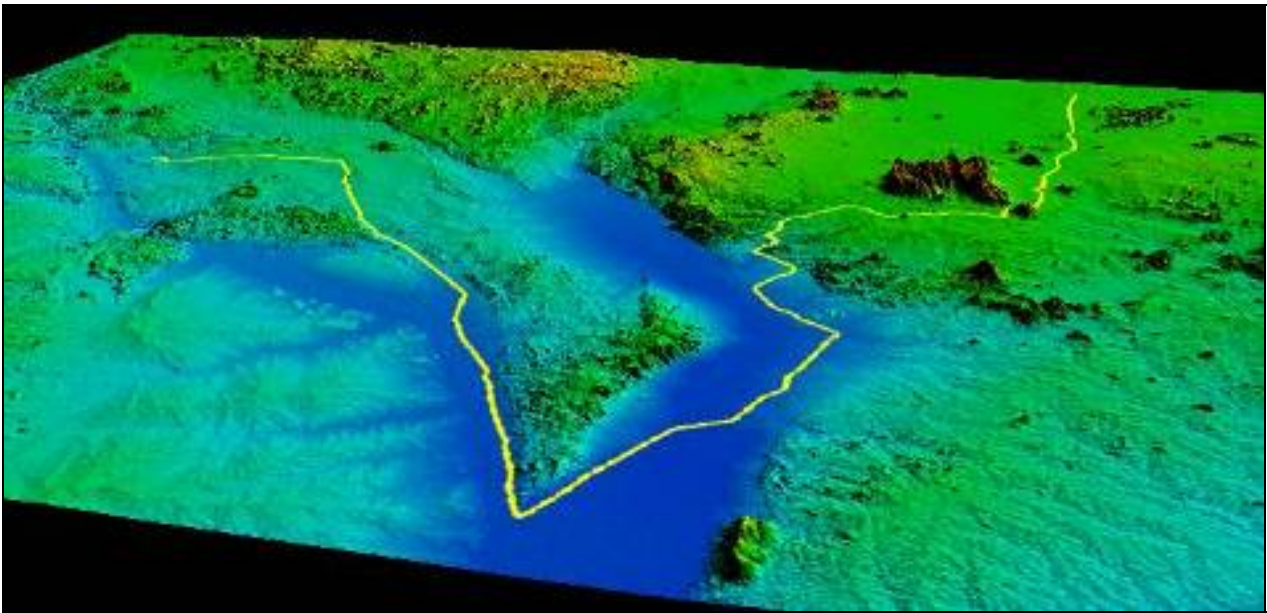


Figure 5: 3D View of Alignment

In conducting these first order studies, the accuracy of the SRTM 90 m Digital Elevation Datasets in terms of bridge crossings and earthworks calculations is sometimes a concern, especially in mountainous terrains. Figure 6 below illustrates the difference in the SRTM and aerial survey data in a case study for a section of fairly flat and mountainous terrain. The SRTM data correlates well with the aerial survey in the flat topography section (first part of figure) but discrepancies are present if the topography is mountainous (second part of figure). The earthworks may therefore be underestimated in mountainous terrain using the SRTM dataset. However, based on case studies a factor of between 1.1 and 2.0 can be applied on the earthworks quantities compensating for the coarseness of the SRTM dataset, depending on the terrain. The “true” earthworks quantities are therefore depicted more accurately.

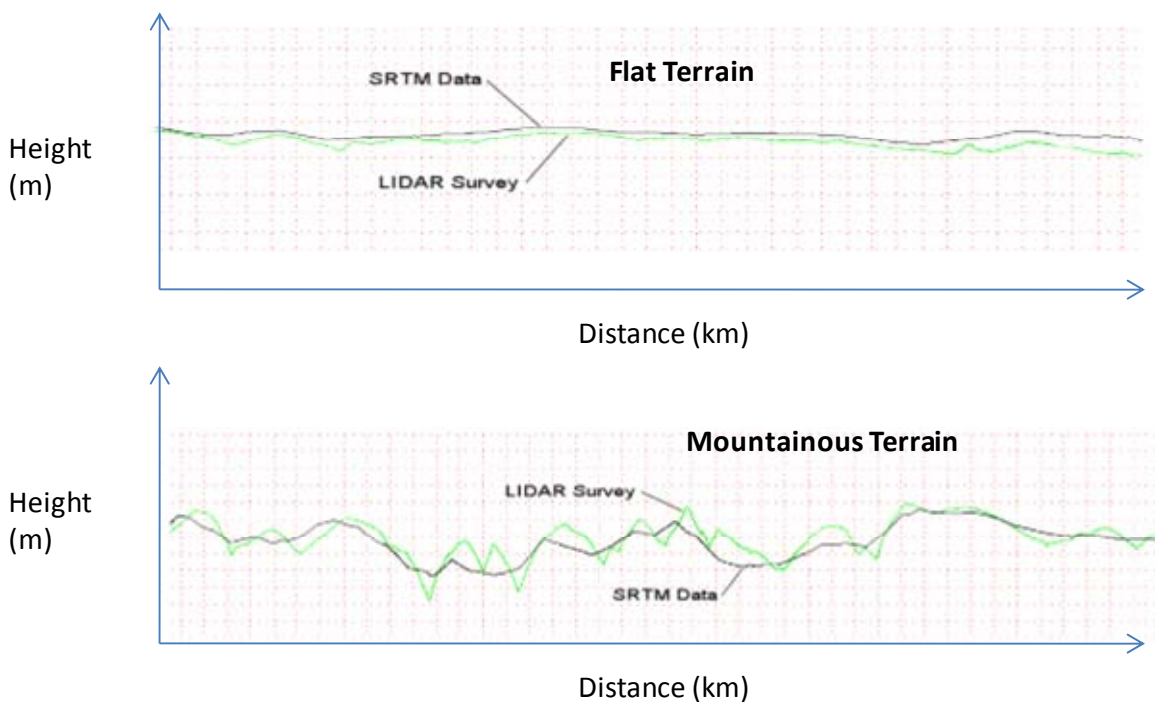


Figure 6: Long section of SRTM vs Aerial Survey Data for Flat and Mountainous Terrain

As discussed before, horizontal and vertical design standards for railways are more stringent compared to, for example, a road, and the challenges to optimize the cost of the alignment in a railway design is greater compared to a road. Large cuts and fills are usually present in a railway alignment through mountainous terrain. Due to the large cuts present, it is important to conduct a first order geotechnical desktop study to try and establish the interfaces of soft, intermediate and hard material in these deep cuttings, in order to get the earthworks volumes and hence cost as accurate as possible. For example, the cost of hard excavation (blasting) is typically ten times that of soft excavations. . Figure 7 shows a 3D example view of the soft, intermediate and hard material interfaces. An example of a cross section is shown where the different material types is cut at different slope angles with hard rock being steep compared to softer material.

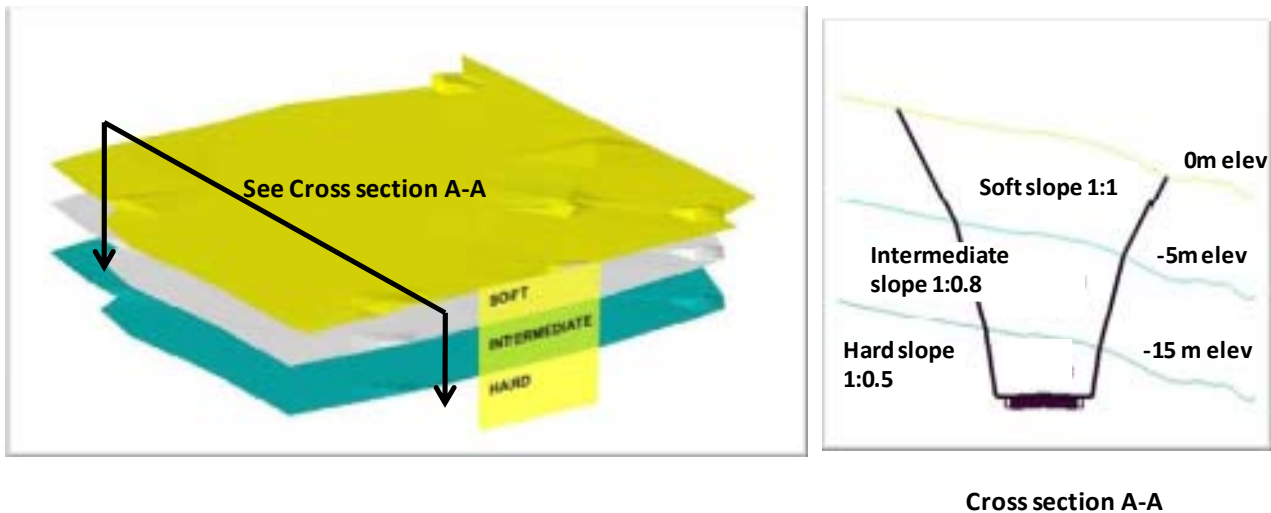


Figure 7: Method used for Earthwork Calculations

A graphical comparison of cut and fill heights on route options is shown in Figure 8, is sometimes useful to appreciate the magnitude of earthworks quantities. The shorter alignment routes to a common point will usually result in more earthworks compared to a longer alignment. These different alignments must then all be compared on a life cycle basis in terms of operating and capital cost to determine the best alignment. Figure 8 shows two alignment options with fill heights (positive value) and cut depths (negative value) relative to the natural topography. The example shows that the alignment on the bottom has high fills and deep cut around km 9 and will probably require tunnels for the high cuts and bridges for the deep fills.

Bridges also play a major role in the makeup of the capital cost of the first order study. These include rail over river bridges; large culverts; road over rail; rail over road and rail over rail bridges.

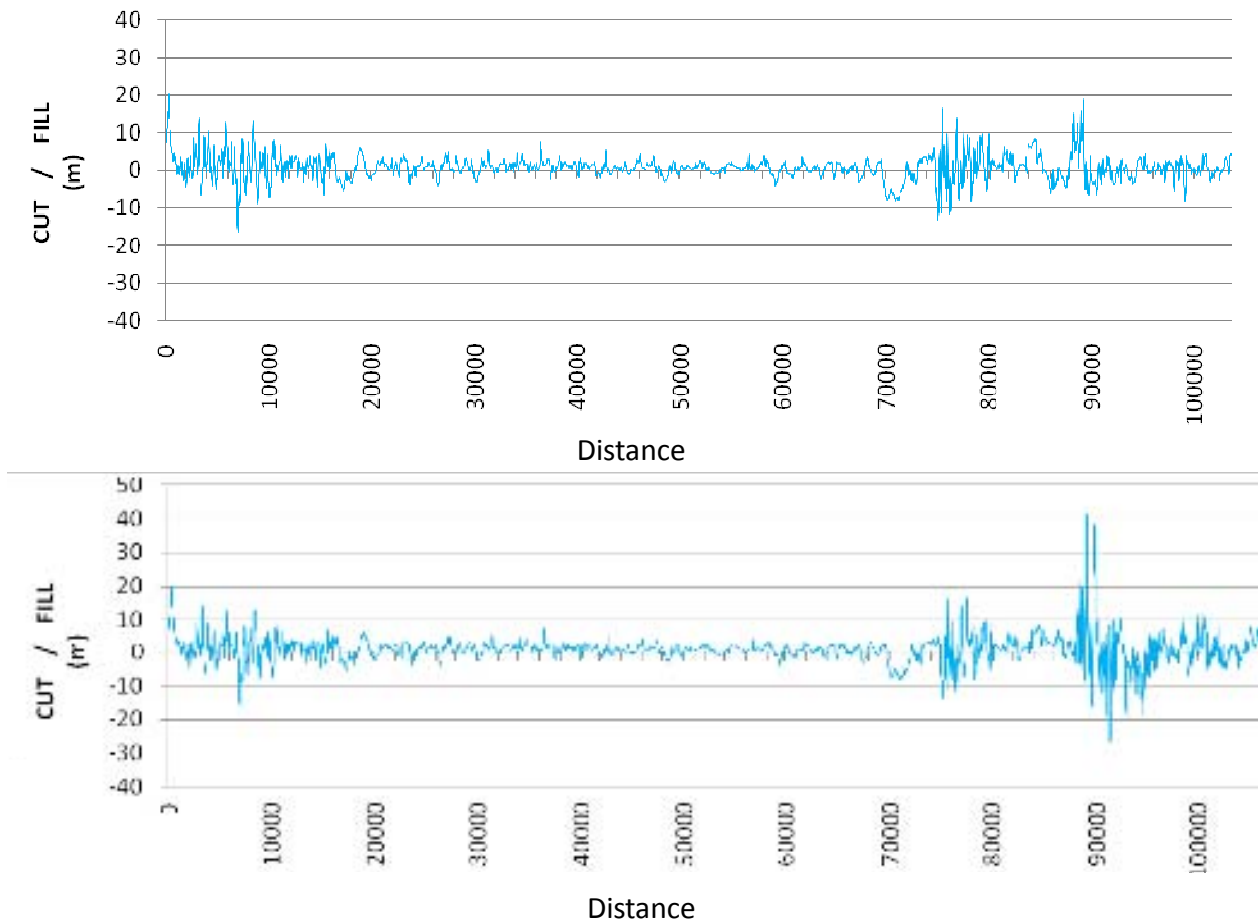


Figure 8: Graphical Presentation of Cut and Fill on Different Routes

4 TRAIN DYNAMIC MODELLING

The operational characteristics of each of the alignments must be determined through detailed train dynamic modelling. The phases of analysis to determine the operational characteristics of the alignments accurately are as follows:

- Establish modelling parameters, including assumptions and the range of variables;
- Determine maximum rolling stock consist sizes for each alignment;
- Overlay infrastructure constraint areas onto alignments to determine possible crossing loop locations; and
- Develop a service pattern.

An example of dynamic modelling results, in terms of consist sizing for a specific alignment, is shown in

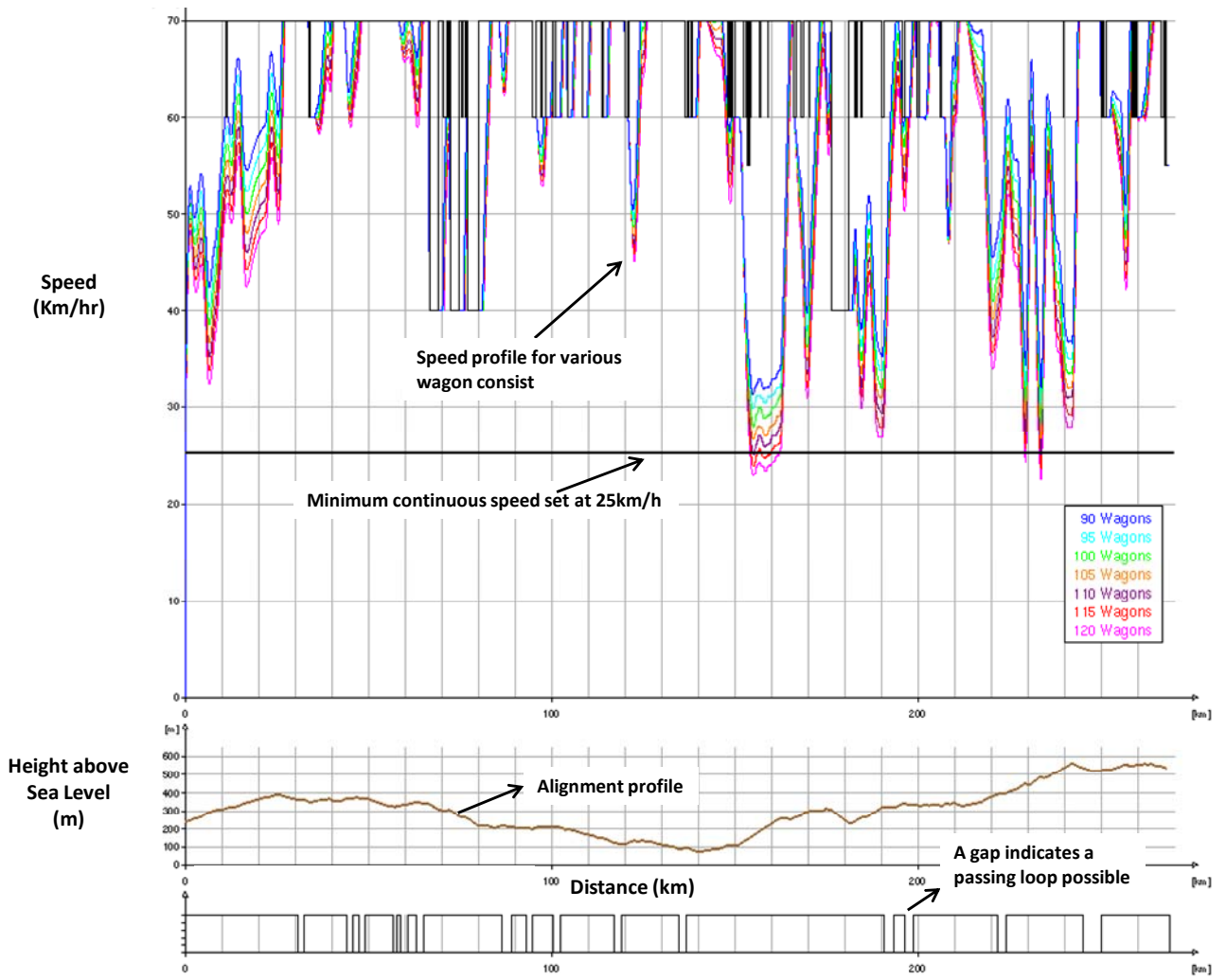


Figure 9.

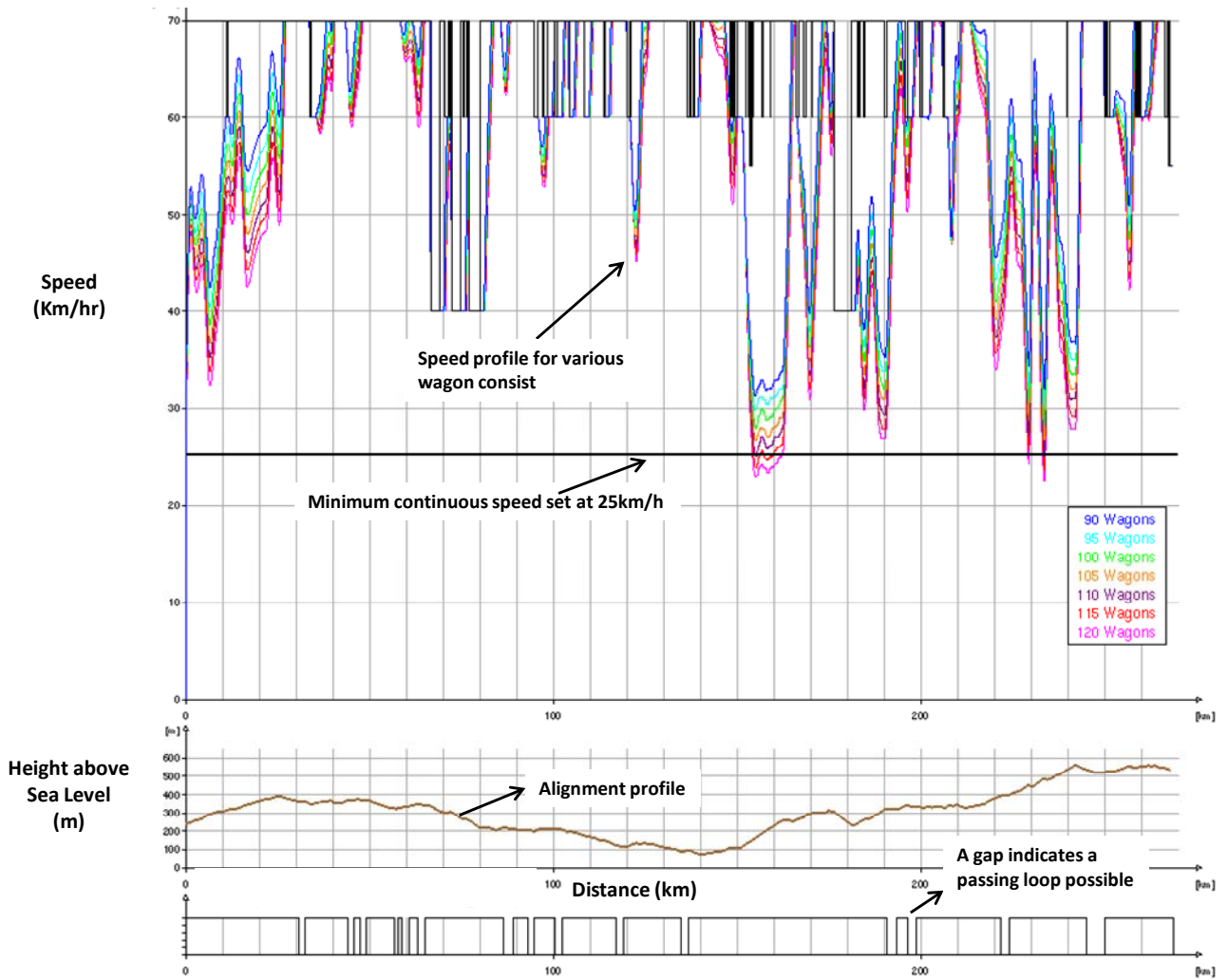


Figure 9: Wagon Graph for the Alignment in the Loaded Direction (Results from OpenTrack)

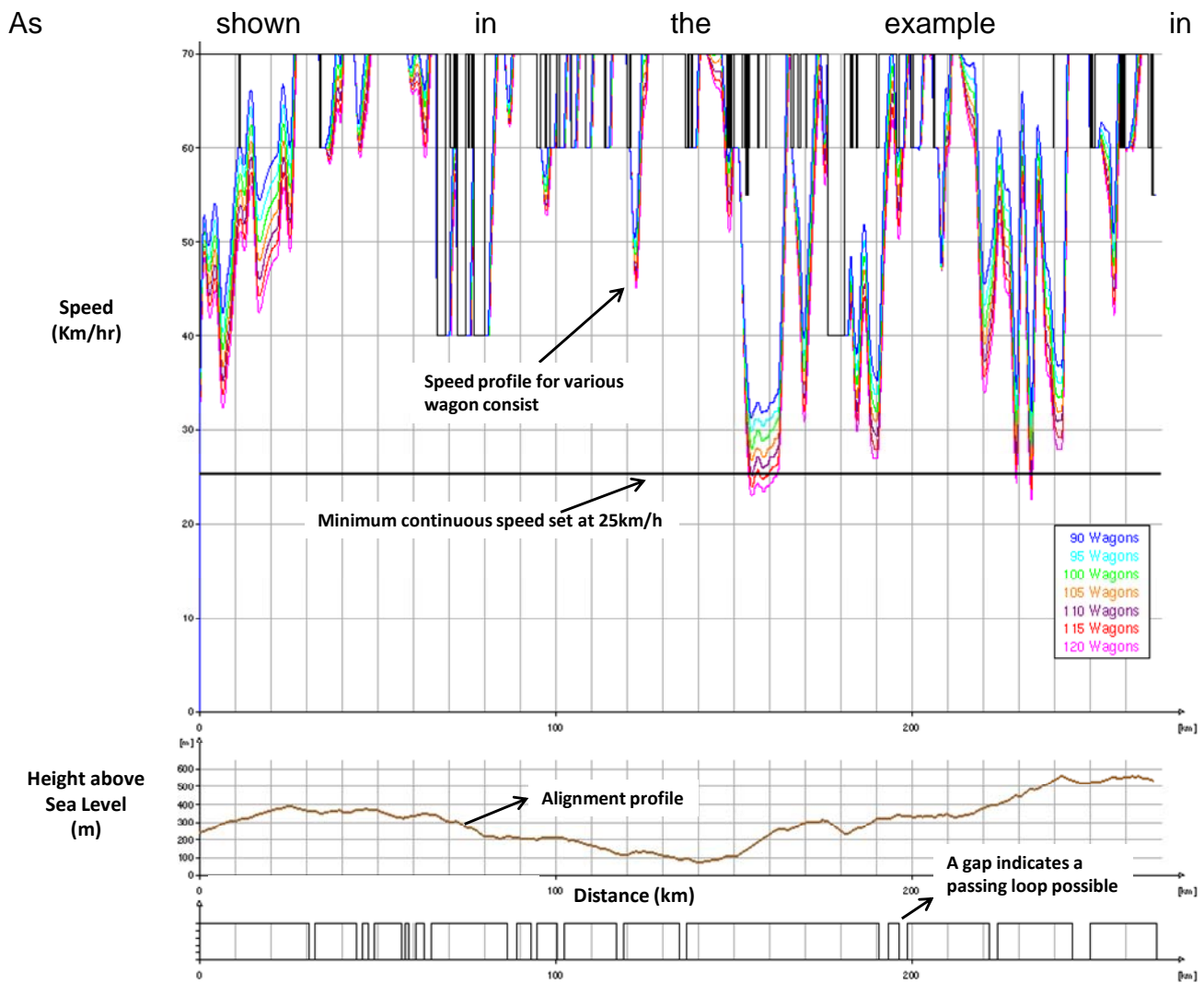


Figure 9, the model allows the trains to travel under the minimum continuous speed. However, in reality, if a locomotive travels under its minimum continuous speed for prolonged periods of time, its traction motor will overheat due to operating at speeds (RPMs) in excess of design, eventually resulting in failure of the traction motor. By analysing the results from the modelling, the maximum number of wagons in each train set for each alignment can be determined.

To determine the required positioning of passing loops, two factors must be considered: firstly, the service frequency (headway) required to achieve the annual tonnage based on the load per train and allowance for other services; and secondly, the physical limitations of the alignment which restrict the positioning of passing loops.

Good railway engineering practices include design parameters to maximize the long-term, efficient rail operations. This includes practices such as not locating crossing loops on steep inclines (where passing trains will be required to stop) and not locating crossing loops on curves. In addition, due to the challenging terrain the alternative alignments must cover, the majority of each alignment is also unsuitable (without excessive cost) for locating a crossing loop, due to the impracticality of constructing a crossing loop on a cliff face. Areas where crossing loops cannot be constructed are defined as blackspots.

Using the travel times between possible crossing loop locations, as determined from the dynamic modelling, the minimum departure frequency achievable is assessed. This is based on the understanding that the longest blackspot (in terms of travel time) dictates the overall system headway. The minimum departure frequency is the sum of the travel times for both a loaded train and an empty train passing through this section, plus an allowance for the empty train to stop and allow the loaded train to pass.

Figure 10 shows an example of a service pattern and placement of loops for a specific alignment. A train departs on the left of the service plan (km 0) and with time arrives at its destination (green line). At the same time an empty train may depart at the destination (blue line) and have to cross with the full train (red vertical line) at designated places (crossing points). The optimization of these crossing points is important to have a stable service plan.

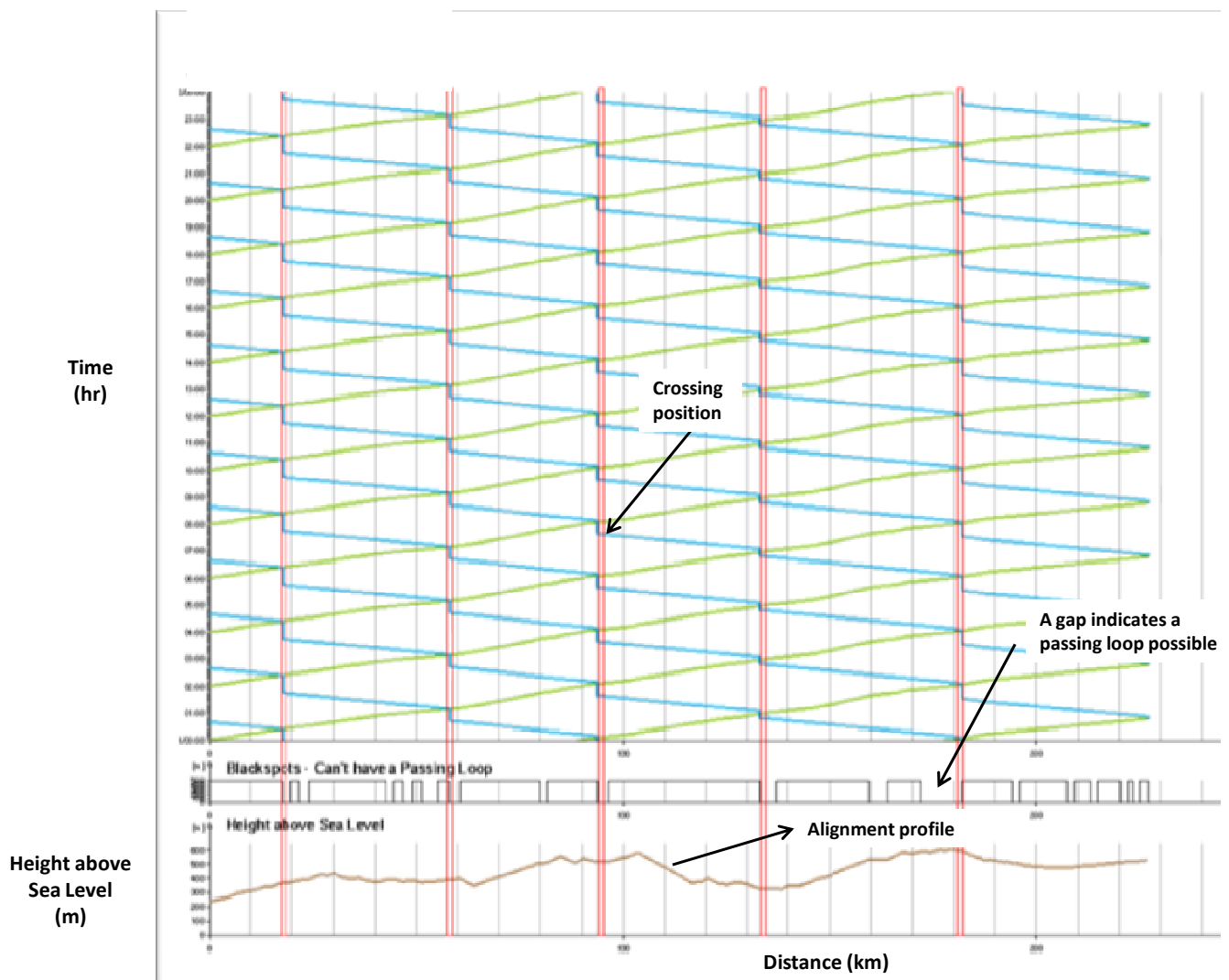


Figure 10: Example of a Service Pattern and Placement of Loops for an Alignment

The outcome of the dynamic modelling is therefore the following:

- Train consist;
- The transit times and rolling stock requirements for the project;
- Fuel consumption; and
- Loop lengths and positions.

5 LIFE CYCLE COST COMPARISON OF ALTERNATIVE ALIGNMENTS

In order to fully compare the life cycle costing of the various alignments, all the rail capital and operating costs must be evaluated in terms of a Present Value (PV) exercise to allow the alternative route alignments to be compared with each other.

Examples of capital cost include:

- Locomotives;
- Wagons;
- Rail Yard; and
- Track, etc.

Examples of operating cost include:

- Crewing;
- Fuel;
- Locomotive maintenance;
- Wagon maintenance;
- Yard maintenance; and
- Business overheads.

Figure 11 shows an example of a PV analysis for various alignments, including the capital and operating makeup of the cost over a certain fixed period.

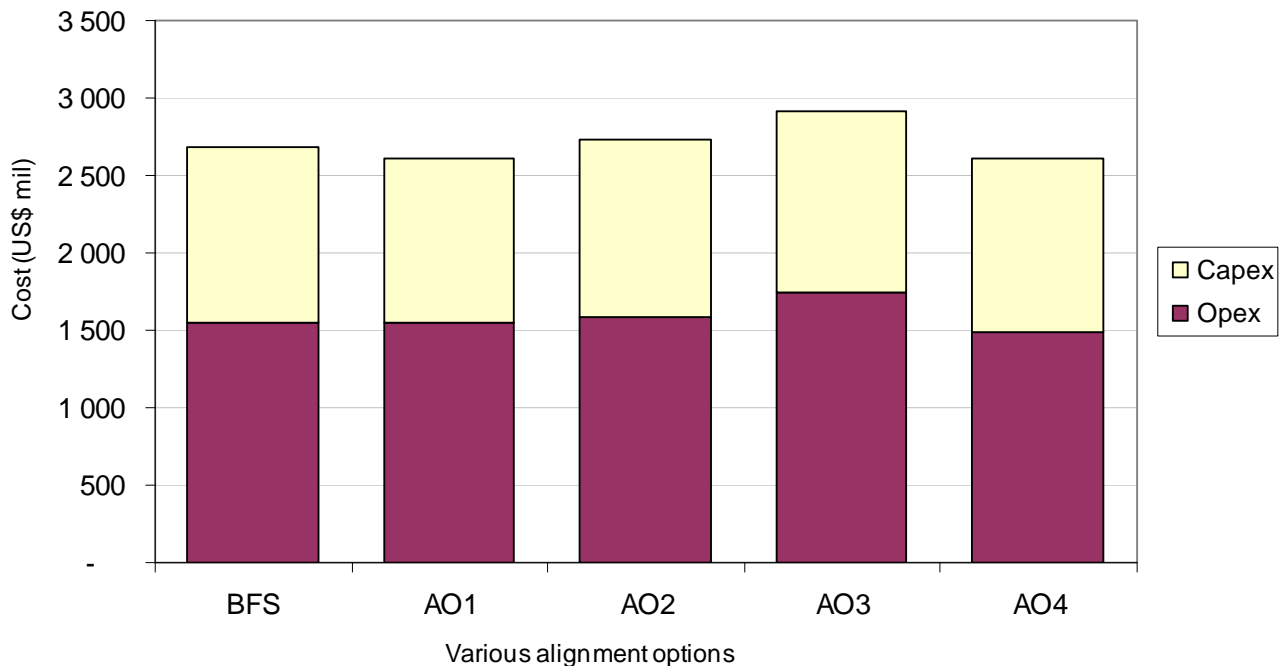


Figure 11: Present Value of Alternative Alignments

6 CONCLUSION

SRTM satellite data can be used very effectively in a first order geometric design study to establish a viable horizontal and vertical rail alignment along with the associated infrastructure cost such as earthworks, bridges, drainage, trackwork, etc. Once the capital and operational cost of various alignments are determined, the life cycle costing of the various alignments is calculated using Present Value (PV) analysis. The analysis allows

the mining companies to make important decisions regarding the viability of the mine i.e. the dollar rate per tonne to import/export the bulk commodity. This may prompt further studies or maybe, more importantly, stop the mine from spending unnecessary further capital on detailed studies that may include costly topographical or geotechnical surveys.

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