Usability of computer optimizing program for road alignment in the planning process

A case study of road 56

Master of Science Thesis in the Master's Programme Infrastructure and Environmental Engineering

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Department of Civil and Environmental Engineering
Division of GeoEngineering
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CHALMERS UNIVERSITY OF TECHNOLOGY

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Master's Thesis 2013:78

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Examensarbete / Institutionen för bygg- och miljöteknik,
Chalmers tekniska högskola 2013:78

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Cover:
An illustration of different alignments generated by Trimble Quantm on a satellite photo (Trimble, 2011).

Chalmers reproservice / Department of Civil and Environmental Engineering
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ABSTRACT

The designer's task in a road construction project is to find a route in plan and profile that takes into account all the requirements, conditions, restrictions and locking points that provide the lowest cost. The purpose of this master thesis is to investigate the usability of the computer software Trimble Quantm in the planning process. The program take into account design standards, terrain, geological, and hydrological data, environmental areas, property ownership together with cost information and creates an optimal alignment between two points. A literature survey, describes how new roads are planned and designed together with information of environmental issues and requirements on the construction. In cooperation with WSP a case study was performed on the suggested new road outside the town Äs located along road 56 between Norrköping and Gävle. Using the optimizing software to find the optimal corridor and alignment for the stretch and compare that with the actual corridors that have been chosen for the stretch in order to evaluate the software. The outcome of the case study indicated that the software suggest approximately the same path for the corridor as the one made by the designers, although the software can't replace an experience designer since the result still needs to be assessed. The software is user friendly and easy to learn. The calculations are fast which enables the designers to investigate and calculate a large number of possible alternatives in less time. The software offers tools that can illustrate how the design of the alignment is influenced by environmental values and by areas of possible geotechnical problem.

Key words: Trimble Quantm, Optimizing, Horizontal and vertical alignment, Planning process, Four stage principle, Road plan, Road 56

Contents

Preface

This master thesis has been carried out by Magnus Olsson as author and University Lecturer Gunnar Lannér as examiner at the Road and Traffic Research Group at Chalmers Technical University. This master's thesis has been written during the period between January to May 2013 under the Department of Civil and Environmental Engineering, Division of GeoEngeering, Road and Traffic Research Group at Chalmers University of Technology, Sweden.

I would like to thank Anders Markstedt at WSP that came up with the idea for the master teases. I also would like to thank Karolina Wettermark at WSP that provided all necessary data together with valuable information during the time for the project.

Göteborg June 2013

Magnus Olsson

Notations

DTM	Digital terrain model
DWG	DraWinG
ECW	Enhanced Compression Wavelet
kkr	Thousand kronor
SEK	Swedish currency
SHP	Shapefile shape format
TIF	Tagged Image File
USD	United States dollar
WSP	Company name

1 Introduction

1.1 Background

The designer's task in a road construction project is to find a route in plan and profile that takes into account all the requirements, conditions, restrictions and locking points that provide the lowest cost. The number of possible routes is unlimited and in practice, there is not enough time and resources in the planning phase of the design to investigate and calculate more than a few possible routes for the final design. As a result the experience of the designer is an important factor to ensure that the most efficient routes are considered and calculated.

By using support from computers is a great opportunity to test a larger number of possible routes, and from that information examine the optimum route. From this information it is possible to achieve significant savings in the design of a road construction for a small cost.

1.2 Aim

The task will be to investigate the usability of computer optimizing software for road alignment in the planning process.

1.3 Method

In a first step a literature survey, that are relating to the production of a road, the environmental issues, requirements and the construction. The literature survey also describes how new roads are planned, designed and built.

A case study of a specific part of road 56 between Norrköping and Gävle will be performed, using alignment optimizing software to find the most optimal corridor and alignment for the stretch and compare that with the actual corridors that have been chosen.

The investigation of the optimal corridor and alignment will be done by using the computer software Trimble Quantm. The program take into account design standards, terrain, geological, and hydrological data, environmental areas, property ownership, and cost information.

The input data to the program will be obtained from data bases, interviews with professional designers, information found on the internet and in literature.

1.4 Limitations

The investigation to find the possible corridors and the optimal alignment within the corridors will be limited to the program Trimble Quantm. The performed investigation and calculations have only been conducted on the road 56. There have been no considerations of intersecting roads.

2 Literature survey

This chapter will explain the basic knowledge on how the designers plans a new road taking to account all the requirements, conditions, restrictions and locking points that provide the lowest cost. The planning process is a procedure that is done in multiple steps.

2.1 From planning to construction of a new road

The planning of a new road starts when there have been identified deficiencies in the transport system. The comprehensive planning process is implemented to answer the question on what needs to be done to solve the problem. First a study called four stage principle is made followed by the feasibility study and the work to develop a road plan. The four stage principle should treat and answer the question of what kind of measures can solve the transport system problem and why it's needed. The process to develop a road plan, treats the question of where the road should be built and how it will be constructed. Before the construction of the project can start the final technical design needs to be described in a construction document. The planning process is illustrated in Figure 2.1.

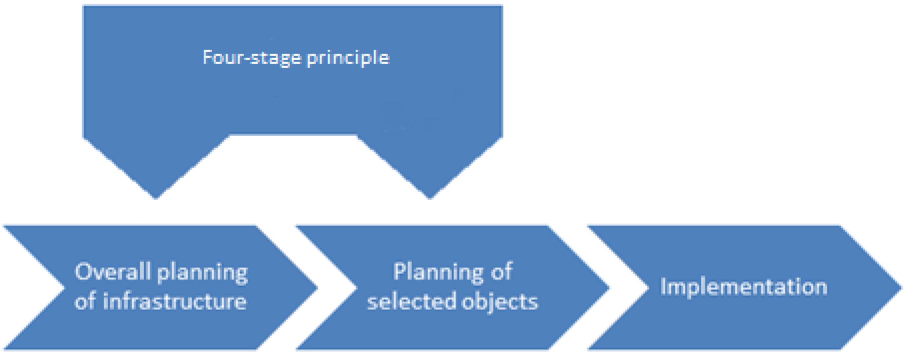


Figure 2.1 Illustrate the process from planning to construction.

2.1.1 Four-stage principle

When there has been a problem identified in the transport system, the comprehensive planning process can start. To investigate how these problems can be fixed, the four stage principle is implemented, this is a new planning process for road projects that were introduced by the Swedish Transport Administration 1 January 2013 (Trafikverket, 2012 (b)). The four stage principle treats the measures that are considered possible to solve the transport system problem. The analysis of the study is made in four steps:

- Step one: **Is there any other solution that can be implemented to solve the problem?** Can the current demand of transport for the stretch be reduced, is it possible to lower the demand of transportation for the stretch or can other modes of transportation be used to solve the problems. Examples of ways to reduce the need of transportation on the stretch can be to investigate if it is possible to move some of the transportations to railway or if it is possible to develop the public transportation.

- Step two: **Is it possible to optimize?** Can the current road network be used in a more efficient way, by for example introduce speed control measures, variable speed or by traffic regulations.
- Step three: **Is it possible to rebuild current route?** Is there a possibility to solve the problem by making improvements or rebuild the current stage. These changes can for example be widening of the existing road, reinforcement and straightening of curves.
- Step four: **Is there a need of constructing a new road?** Is there a need for large reconstruction of the road or should there be an investment in a new road to solve the problem.

The four stage principle will give the answer to why a road project is needed. The study investigates how deficiencies in the transport system can be solved. Primary the problems are trying to be solved with the first two steps, if the problem can't be solved with these steps, step three and four are used which are a more concrete building measure (Trafikverket, 2012 (b)).

2.1.2 Planning process

A new road will be planned according to a process that is governed by laws and which ultimately leads to a road plan. This process is called the planning process and work to develop a road plan. The planning process starts after the result of the four stage principle shows that a new road or a major reconstruction of the current road is needed. The process is illustrated in Figure 2.2. The planning process investigates where and how the road should be built. The time for the process depends on the number of studies required, if there are alternative routes, how large the available budget is and if there are some opponents to the project. The result of the planning process is the basis of the work that finally is presented in a road plan (Trafikverket, 2013).

Figure 2.2 Shows the planning process.

During the investigating work the planners consider the conditions for the construction and the problems that must be solved. The planners try to create a good understanding of the values and interests that are located in the area together with areas that can cause conflicts. In areas where a new road needs to be built in order to solve the transport problem, alternative routes are investigated. The investigation includes a description of the consequences for each the alternative routes. Great effort is put on the general interests when selecting the alternative route, for example the land use, road safety, availability and environment. In the investigating work the planners studies different proposals for the designs of the road for example the width of the road, number of lanes, tunnels and bridges together with the types of intersections that are going to be used. Usually actions on the existing road are included as an option. There are also preliminary surveys and studies done in adjacent to the planned route to receive for example information on the geotechnical conditions or archaeological remains (Trafikverket, 2012 (b)).

In the early stage of the planning process there must be documents developed that describe how the project may affect the surrounding environment. After these documents have been developed the provincial government decide if there is a significant effect on the environment, if so there need to be an environmental impact assessment developed which describes the project's environmental impact and suggest precautionary and protective measures. Information on environmental impact assessment can be found in Chapter 2.1.4. During the process there are dialogues with government agencies, organizations and other stakeholders to obtain their views and knowledge (Trafikverket, 2012 (b)).

According to the environmental act some major road projects needs to receive an authorization from the government before the work with the road plan can start. The planners rank the alternatives and present a report to the government with a description of the different alternatives together with an associated environmental impact assessment for each of the alternatives. The government decides if the road is allowed to be built in a certain location. After the decision the work continues to develop a more detailed location and design for the road (Trafikverket, 2012 (b)).

The road plan will include a map of the area that describe in detail the alignment for the road along with information of the land that will permanently be used for the structure. The road plan also will include information of the land used for the roads that are temporarily needed during the construction together with a consultation report that shows all the consultations that have been made and how these has influenced the design of the road, for example reduction of noise pollutions. The report also needs to include a description of the aspects that not have been considered and information of safety measures that have been assessed not to be justified (Trafikverket, 2012 (b)).

After the road plan is finished and the project has available funding, the road plan will be sent to be determined by the transport administration. The project will be determined if the transport administration concludes that the benefits of the project are larger than the inconvenience caused on individual interest.

2.1.3 Construction document

The constructions documents describe the final technical design for the road project. The documents must follow the information presented in the road plan. There are only a limited deviation allowed, if there are larger changes of the project the road plan may need to be revised in order to be valid and new constructions documents needs to be made (Trafikverket, 2012 (b)).

2.1.4 Environmental impact assessment

The purpose of an environmental impact assessment is to contribute to the environmental adaption of the project and through consultation with the stakeholders provide relevant knowledge and ability to influence the project. The environmental impact assessment includes identifying and describing the project's possible environmental impact. The assessment is used to support the environmental adaption in the planning process and present a basis that can be used for the overall assessment on the impact on the environment and human health (Trafikverket, 2011 (b)).

2.2 Governing regulations

The most important regulations for road constructions are presented in this chapter. The requirement is to ensure that the construction and function of the road will last for a long time from both the structural and environmental standpoint.

- *According to 1 chapter 10 § in the road act (1971:948)* With building of roads referred to construction of a new road or reconstruction of a road. New road may be build, if the road is needed for general means of communication or otherwise likely to have particularly importance for the public. A road may be rebuilt, when justified in the public interest. An action on an existing road is not considered to be road construction if

    1. Action results in only marginal additional impact on the environment.

    Or

    2. The property owners or holders of special rights in writing admitted that land or other space may be utilized.

- *According to 1 chapter 11 § in the road act (1971:948)* Question about road construction is tested by the Swedish Transport Administration, after consultation with the provincial government. If the Transport Authority and the provincial government have different views, referred the question to the Government.
- *According to 1 chapter 13 § in the road act (1971:948)* When a road is built it should be given a position and be designed so that the purpose of the road is achieved with minimum damage and inconvenience without unreasonable expense. Consideration should be given to urban and landscape together with the natural and cultural values.
- *According to 6 chapter 3 § in the Environmental Code (1998:808)* The purpose of an environmental impact assessment is to identify and describe the direct and indirect effects of a proposed activity or action may result in partly on humans, animals, plants, soil, water, air, climate, landscape and cultural environment, the management of land, water and the physical in general, partly on other management of materials, raw materials and energy. Then, an overall assessment of these effects on human health and the environment are described based on the findings in an environmental impact assessment.

2.3 Road construction and functions

The design of a road structure consists of different parts, the foundation, substructure, terrace surface, superstructure and slopes. The different parts of a road structure are illustrated in Figure 2.3.

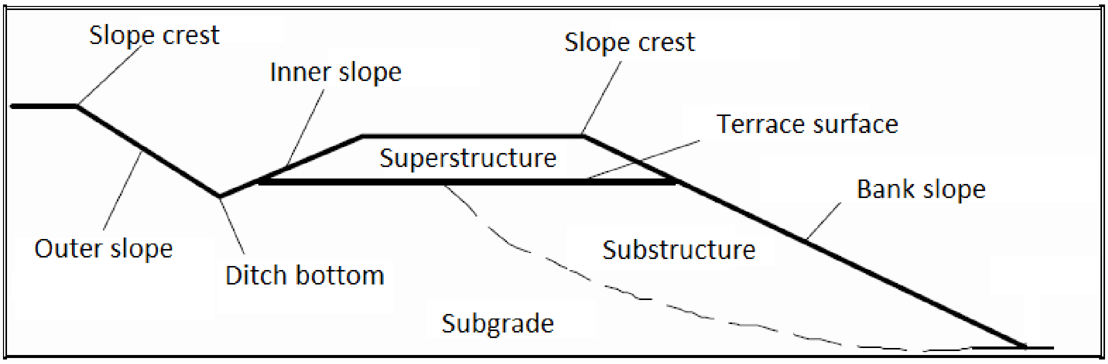


Figure 2.3 A traditional cutting of a simple road structure.

The foundation consists of the existing ground that the proposed road is supposed to rest on. In Sweden the foundation usually consist of rock, clay or moraine. The substructure is the surface that is used to compliment the foundation to obtain the terrace surface at the desired level. The foundation has restrictions on the durability, to achieve these requirements there are some reinforcement methods that can be used: reducing the pressure on the surface, bring down the pressure to firmer materials and by backpressure. Reducing the pressure on the surface can be done thru excavation, usage of light filling material or a combination of both methods. Bring down the pressure to firmer materials can be done by excavation and backfill, filling by depressing/displacement, piling or by usage of lime cement columns. Backpressure can be done by usage of pressure banks (Granhage, 2009).

The superstructure usually consists of three different layers: the subbase, base course and wearing course. The different layers are illustrated in Figure 2.4. The reinforcement layer acts as a protective and drainage layer to prevent moisture and fine material to penetrate into the base course. The base course and the subbase are used to distribute the load evenly over the subgrade. The base course supports the wearing course, which means that the layer also supports the traffic load; the base course can either be bound or unbound. The bound base course is hold together with different mixtures of bitumen, which is the most common type of base course. The unbound base course is most common on smaller roads that has no bitumen layer and is often called gravel roads (Granhage, 2009).

Figure 2.4 The basic design of the superstructure, containing the distribution of the most common layers.

2.4 Geometric design

The geometric design means the design of road in a holistic perspective. The basics of geometric design is to have knowledge of road design requirements for geometry and knowledge of what type of traffic that is intended to use the road. Additional factors that will be added for the design is the use of traffic control, such as road markings and signposts. Furthermore the design should take into account quality, good environment and aesthetics. Since roads mostly are financed by public funds, the economic valuation is very important. There are different design standards when designing a road. According to the Swedish guidelines the design levels are good, less good or low (Robinson & Thagesen, 2004).

The geometric design is usually divided into three major areas: cross section, horizontal and vertical alignment. The cross section takes into account how wide the road needs to be, which cross fall that should be used and how the design of the trenches and slopes should look like. The horizontal alignments describe the design in plan or in a map. It shows the route through the countryside with curves and straight lines. The vertical alignment shows the design of the road in height along the stretch. It shows vertical curves, slopes of hills, valleys and crest. The alignment is three-dimensional and for the final design of the alignment, a combination of the horizontal and vertical alignment is used. In traditional alignment design these lines are treated separately, but this does not mean that they are independent of each other. When designing the alignment it is important to work and make adjustments with both lines simultaneously or alternately (Robinson & Thagesen, 2004).

2.4.1 Cross section

The general principles when designing the cross section is that the width of the road should be minimized in order to reduce the construction and the maintenance cost of the road, still the road needs to maintain the level of service that it is designed for. When selecting the width of a road there are different factors that needs to be taken in to account: classification of the road, traffic, vehicle dimensions and vehicle speed (Robinson & Thagesen, 2004).

The classification of the road means which level of service the road will be designed for, higher level of classification means higher level of service is expected which results in that the road needs to be wider. When taking into account the traffic means that the volumes of heavy traffic affect how wide the road needs to be. If the amount of heavy traffic are high the overtaking of slow vehicles are more frequent. Vehicle dimensions are also affecting the dimensions of the road. Tracking errors and normal steering deviations on particularly heavy vehicles results in that the clearance between passing vehicles can be reduced, which leads to that the road needs to be wider. When the speed of the vehicle increases the driver has less control of the vehicle leading to reduced clearance between the vehicles, with the consequence that a wider road is needed (Robinson & Thagesen, 2004).

2.4.2 Road alignment

The designer has the opportunity to adjust the alignment of the road through the landscape to make it as safe and economical as possible while still fulfil the technical requirements of the construction. The alignment should be adjusted so that it blends in with the surroundings, by allowing it to follow the natural lines in the terrain. This also has economic benefits because the need of excavation and the amount of material needed can be decreased. There is also a goal to design the road to provide good visual management as well as clear signals to the users about appropriate driving behaviour and speed (Vägverket, 2004).

When working with the design for a road project the first step is to set a main direction for the road (often east or north). This enables more easily to define right or left curves and up or down hills etc. there is also a possibility to introduce sign rules to enable simpler calculations (Wengelin, Berntman, & Lannér, 2000).

When selecting the alignment for a new road, the designer normally starts to define a number of possible corridors between the suggested start and finish points for the new road. Next step is to select the best corridor and within it define one or more different alignments. These alignments are then compared, and a final selection is made for design purposes. The process involves continuous searching and selecting, using increasingly more detailed knowledge at each decision-making stage (Robinson & Thagesen, 2004).

Horizontal alignment

The horizontal alignments basic elements are a series of intersecting tangents and circular curves that are connected with or without transition curves. An example on the design of the horizontal alignment for a road can be seen in Figure 2.5. The aim is to design the horizontal alignment to an economic standard that is consistent with the topography to minimize the earthworks needed and to provide good drainage. The design selected are based on a given standard of the road, this means that the design should extend throughout a section of the road without no sudden changes from easy to sharp curves to achieve a uniform operating speed. Where sharp curves are unavoidable, the recommendation is to design a series of curves with decreasing radius (Robinson & Thagesen, 2004).

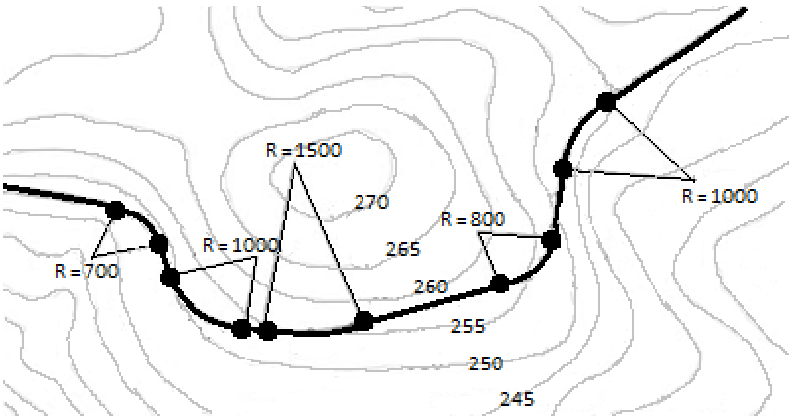


Figure 2.5 Shows an example of the horizontal alignment for a road.

Vertical alignment

The basic elements of the vertical alignment are the gradient and vertical curvature. An example of the design for the vertical alignment can be seen in Figure 2.6. The gradient is related to the level of service and the vertical curvature is related to comfort criteria and the sight distance. The vertical alignment influences the construction cost, traffic safety and the vehicle operating cost. The goal is to design the vertical alignment to an economic standard consistent with the topography and need of traffic (Robinson & Thagesen, 2004).

As for the horizontal alignment the recommendation is to try to design the alignment as uniform as possible, having as large radius as possible without any sudden changes. Although this is a recommendation, it has not the same importance as for the horizontal alignment, since the vertical curves does not have the same impact on the speed of a vehicle. A risk when using to large radius is that the drainage can be insufficient since the flat inclination can limit the runoff (Wengelin, Berntman, & Lannér, 2000).

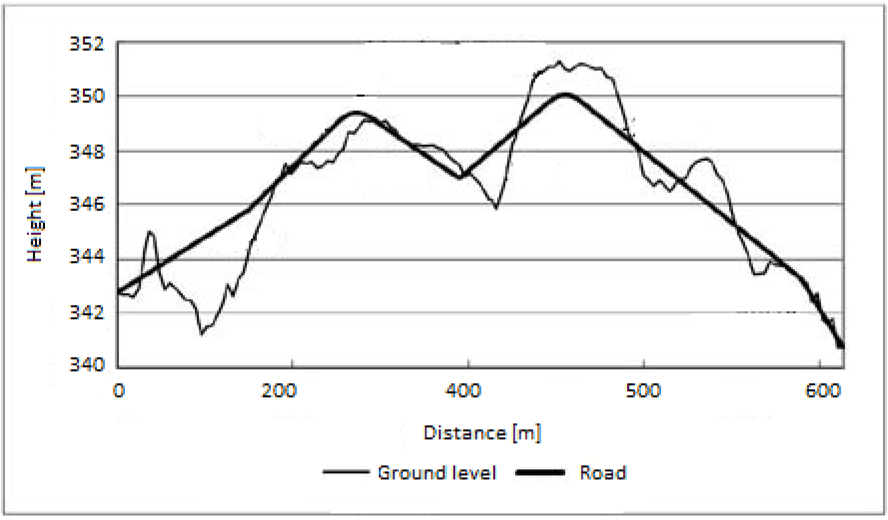


Figure 2.6 Shows an example of the vertical alignment.

3 Case study of road 56

The chapter describes the area around the town of Äs where the case study will be performed. The method for the case study together with information of the environmental aspects, possible issues, requirements and technical information for road 56 will also be described.

3.1 Introduction

The case study has been performed on Road 56 between Bie and Stora Sundby. Road 56 is the main road between Norrköping in the south and Gävle in the north. The road is a part of the Swedish national road network called the straight line. The total length of the road is 295 kilometre and is part of a developing program for collision-free road. To increase the safety, the road is rebuilt in stages (Trafikverket, 2011 (a)).

The stage between Bie and Stora Sundby is trafficked by 4000 vehicles per day with a proportion of 20 percentage heavy traffic; this indicates that the road has an important role as freight route. On the stretch there is a proposal to build a new road that will pass outside the town Äs, which is located between Bie and Stora Sundby, see Figure 3.1. WSP has been commissioned to develop possible corridors for the new road outside Äs. The new road will be approximately 7 kilometres depending on which of the corridor that are selected. The area around Äs offers many challenges where different environment aspects and interests need to be accounted for when suggesting where the new road could be built.

This makes the stage an excellent object for studying if there are some other possible corridor and alignment that make smaller impact on the environmental values and avoiding the possible geotechnical problem zones.

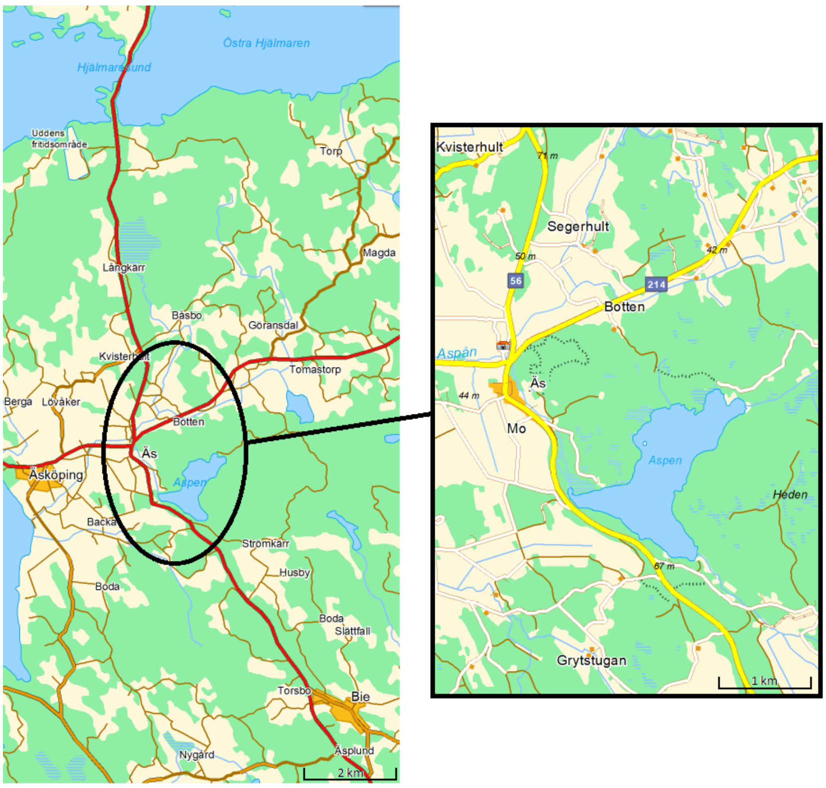


Figure 3.1 Shows the stretch between Bie and Stora Sundby and also a zoomed in picture of the area around Äs (modified after (Hitta.se, 2013)).

3.1.1 Local geology

The description of the local geology is based on SGU earth map, see Figure 3.2. Around Äs there are large areas of agricultural land. The area west of the existing road 56 is dominated by silt and glacial clay, east of the road and around the lake Aspen the area is dominated by sandy moraine and bedrock. The existing road 56 follows a glaciofluvial esker that is surrounded by portions of sand (Trafikverket, 2011 (a)).

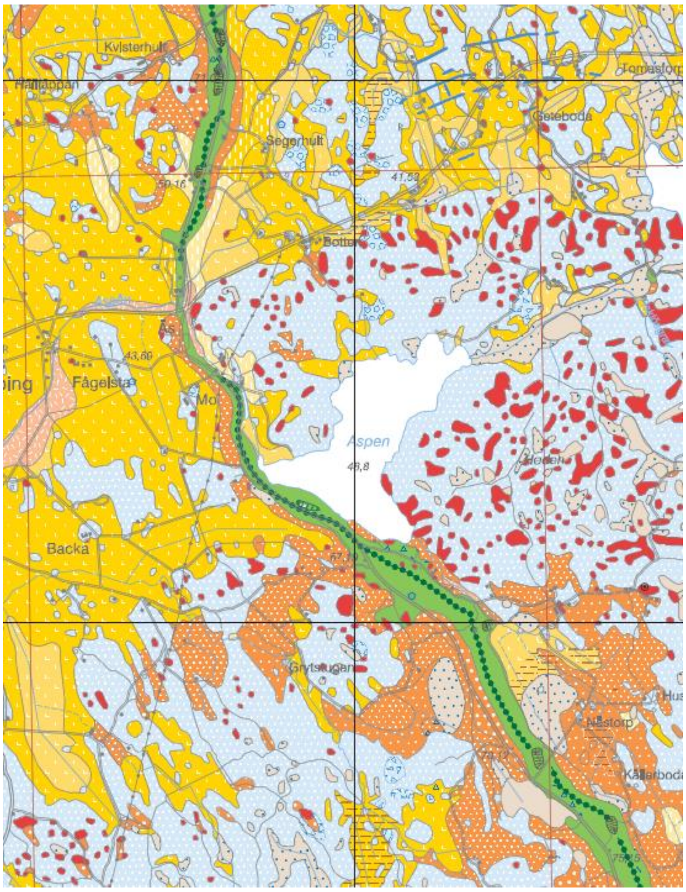


Figure 3.2 Shows the earth map of the area within the geographical boundary (SGU, 2013).

3.1.2 Sensitive environmental areas

In the area around Äs there are many different issues to consider. There are cultural, landscape and natural environmental values that need to be accounted for when planning the new road. There are also areas with possible geotechnical issues around Äs. The goal is to avoid these areas as much as possible. There are different conservation value for the areas making it possible to optimize the corridor and the alignment to interfere as little as possible with the sensitive areas. The impact in environmental zones are considered to be limited when reconstructing existing road (Trafikverket, 2011 (a)). The cultural, landscape and natural environment values for the target area are described in the Chapters 3.5.5-3.5.7 together with a description of the possible geotechnical issues in Chapter 3.5.4.

3.2 Data collection methods

The different methods that have been used for collection of data is study of maps of the target area, interviews of persons involved in the project and drawings provided by WSP, these are briefly discussed below.

3.2.1 Study of maps of the area

The maps studied for data collection for the cultural-, landscape- and natural environmental areas and the maps describing where the possible geotechnical issues is located where provided by WSP. The soil map was provided by the geological survey of Sweden.

3.2.2 Interviews

The search for information was done by e-mail and telephone interviews with persons involved in the project together with persons that have knowledge within the field of geotechnical issues and road construction.

3.2.3 Data provided by WSP

WSP provided the digital terrain model for the area together with digital files with information of where the sensitive areas are located. The digital terrain model where given in DTM format and the data files for the environmental areas which include the areas of natural, cultural and landscape environmental issues and areas where there are possible geotechnical issues were given in SHP files. The files could be directly imported into Trimble Quantm. WSP also provided SHP files with the suggested corridors that will be examined together with files in DWG format with the existing roads, rivers and lakes within the target area. Aerial photos of the area where also provided by WSP, these where given in TIF format.

3.3 Usage of Quantm

The optimizing process has for a long time been an important factor and is widely used when designing a new road. The models assist the designer and planners to evaluate and choose between different possible alignments between two points. Since there is an unlimited number of a lines in space between two points the task of selecting the most appropriate alignment, that's consider all the specifications and environmental requirements is a difficult task (Jha, Schonfeld, Jong, & Kim, 2006).

Due to the development of computers and the growing availability of high resolution digital terrain models has made the usage more realistic and practical. The models help provide a large number of paths (Akay, Karas, Sessions, Yuksel, Bozali, & Gundogan, 2004).

For the study purpose Trimble Quantm version 7.3.0.274 is utilized. Trimble Quantm is a system that in a simultaneous analysis takes engineering, environmental, social and economic factors into account when planning a new road. Trimble Quantm allows the planners to examine all alternative routes between two points and select the most appropriate alignment and corridor based on the total cost for the project (Trimble, 2011).

A visualization of the Trimble Quantm desktop can be seen in Figure 3.3 which illustrating the different tools that are used when constructing a model.

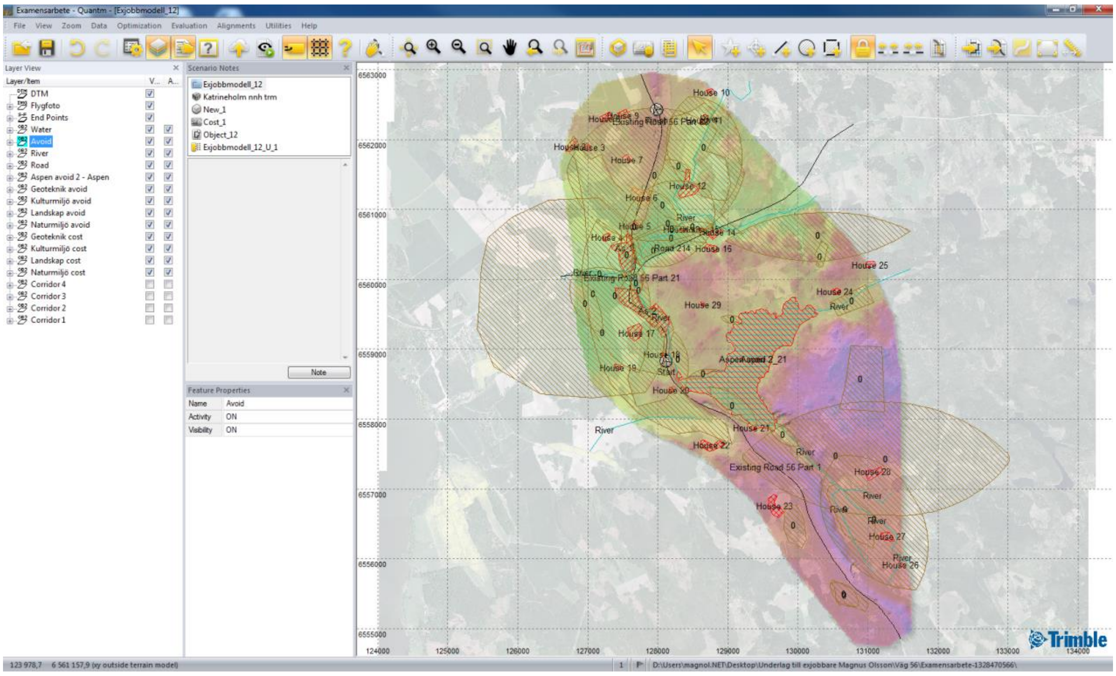


Figure 3.3 An overview of Trimble Quantm desktop window and tools used for construction of the model.

3.4 Construction of the model

The construction of the model was done in multiple steps explained below. The model was constructed with a combination of already completed files for the zones with possible environmental or geotechnical issues and files that where done by hand in the software Trimble Quantm.

1. The digital terrain model was imported into Trimble Quantm, for more information of the digital terrain model. More detailed information of the digital terrain model can be found in Chapter 3.5.3.
2. The format of the satellite photos where changed to ECW format using the software Global Mapper version 13.00 to make it possible to import the photos into Trimble Quantm.
3. The start and finish points where entered together with the template for the road. Detailed information of the start and finish point together with the template can be found in Chapter 3.5.9.
4. The general costs parameters together with the geometric parameters where entered. The parameters are shown in Chapter 3.5.1.
5. The SHP files for the possible cultural- (see Chapter 3.5.5) landscape- (see Chapter 3.5.6) natural- (see Chapter 3.5.7) environmental values were imported to the model together with the possible geotechnical issues (see Chapter 3.5.4). These where entered as avoid zones with different status of high or medium.
6. Rivers, the lake Aspen and the existing roads are drawn in the software using the satellite photo.
7. The town Äs, houses outside the town and the lake Aspen where identified using the satellite photo, after identification they were given avoid zones. The avoid zones can be found in Chapter 3.5.8.
8. The area cost zones were imported using the SHP files for the possible cultural- landscape- natural- environmental values and the geotechnical issues. The increase of cost when entering a zone can be found in Chapter 3.5.2.
9. The corridors given by WSP were imported to the model.

3.5 Data input

The chapter will present the value for the geometric and cost parameters used in the model. The digital terrain model together with the data for the environmental and geotechnical issues are presented. Furthermore the avoid areas and the technical specifications are presented.

3.5.1 General input data for Trimble Quantm

The input values for the basic cost parameters are presented in Table 3.1. The parameters are entered under the “cost parameters” toolbar in the software. Parameters for the geometric design of the horizontal curves together with the type end length of the transition curves are presented in Table 3.2. The geometric parameters for the vertical design can be found in Table 3.3. The parameters are entered under the “geometric parameters” toolbar. In the tables there is a description for the different parameters together with the value. The values given from (Trimble, 2012) are converted from USD to SEK with an exchange course of 6,58 SEK for 1 USD.

Table 3.1 Shows the basic cost parameters that were used in Trimble Quantm.

Cost parameters			
Pavement	**Value**	**Unit**	**Description and source of value**
Pavement	1750	Kr/m^3	The pavement cost is the cost of placing one cubic meter of pavement and compacting it to the specified thickness (Markstedt, 2013).
Fill			
Rate	10	Kr/m^3	(Trimble, 2012).
Side slope	55	%	(Trimble, 2012).
Step height	6	m	(Trimble, 2012).
Step width	2	m	(Trimble, 2012).
Earth movement costs			
Haul	3	Kr/m^3/km	Haul is the cost of transporting one cubic meter of usable material along the alignment to the point where it is needed (Markstedt, 2013).
Dump	9	Kr/m^3	Dump is the cost of removing excess or unusable material (Markstedt, 2013).
Borrow	94	Kr/m^3	Borrow is the cost of purchasing material and transporting it from an external site (Markstedt, 2013).
Culvert			
Culvert	987	Kr/m	The cost per meter for the culvert (Markstedt, 2013).
Portal	1645	Kr	The cost for the portal (Trimble, 2012).
Bridge			
Bridge	65800	Kr/m^2	The costing of bridges assumes a fixed cost per unit area of deck (Markstedt, 2013).

Tunnel			
Tunnel	329000	Kr/m	The material excavated from the tunnel is assumed to be entirely usable for fill (Markstedt, 2013).
Portal	2102600	Kr	The cost for the portal (Markstedt, 2013).
Wall			
Wall	1974	Kr/m^3	The costs associated with a retaining wall (Markstedt, 2013).
Material			
Silt/loam	13	Kr/m^3	The cost for the material (Trimble, 2012).
Clay	43	Kr/m^3	The cost for the material (Trimble, 2012).
Broken rock	51	Kr/m^3	The cost for the material (Trimble, 2012).

Table 3.2 *Shows the basic geometric parameters for the horizontal curves together with the transition type and length used in Trimble Quantm.*

Geometric parameters			
Horizontal	**Value**	**Unit**	**Description and source of value**
Curves			
H rad	700	m	Minimum horizontal radius of curvature. The value determines how closely the alignment follows the natural surface (Trafikverket, 2012 (a)).
Super	4	%	The super elevation for the minimum radius (Trafikverket, 2012 (a)).
Transition			
Type	Clothoid		The type of transition curve (Trafikverket, 2012 (a)).
Trans. Length at min rad	250	m	Transition length at minimum radius (Trafikverket, 2012 (a)).

Table 3.3 Shows the basic geometric parameters for the vertical design used in Trimble Quantm.

Geometric parameters			
Vertical			
Grades			
Downhill	-6	%	Maximum gradient downhill (Trafikverket, 2012 (a)).
Uphill	6	%	Maximum gradient uphill (Trafikverket, 2012 (a)).
Sights dist.	100	m	Minimum sight distance (Trafikverket, 2012 (a)).
Curves			
Crest	6000	m	Minimum vertical radius (Trafikverket, 2012 (a)).

3.5.2 Costs for environmental and geotechnical issues

The increase of the cost per square meter, when entering zones with possible cultural-, natural-, landscape environment values together with the possible geotechnical issues are presented in Table 3.4.

Using the SHP files for the possible environmental or geotechnical issues, the zones where given an area cost. This will increase the cost for the new road if the alignment for the road will pass through a zone. The increase of the cost will depend on how much intrusion there is in the zone.

Table 3.4 Shows the extra cost when entering a zone with either environmental value or geotechnical issues.

Area cost type	**Value increase**	**Unit**	**Description**
Geotechnical issues	30%	Kr/m^2	The increase of cost when entering the zone (Wettermark, 2013).
Cultural environment	20%	Kr/m^2	The increase of cost when entering the zone (Wettermark, 2013).
Natural environment	5%	Kr/m^2	The increase of cost when entering the zone (Wettermark, 2013).
Landscape environment	5%	Kr/m^2	The increase of cost when entering the zone (Wettermark, 2013).

3.5.3 Digital terrain model

The digital terrain model was provided by WSP. The model is illustrated in Figure 3.4. The model where constructed from laser scanning of the area made by Lantmäteriet (Wettermark, 2013).

A digital terrain model is a digital representation of the surface area. The model consists of an irregular network of triangles between the points where each triangle is regarded as a flat surface. The points together with the lines between the points are the input when creating a digital terrain model (Klang, 2006).

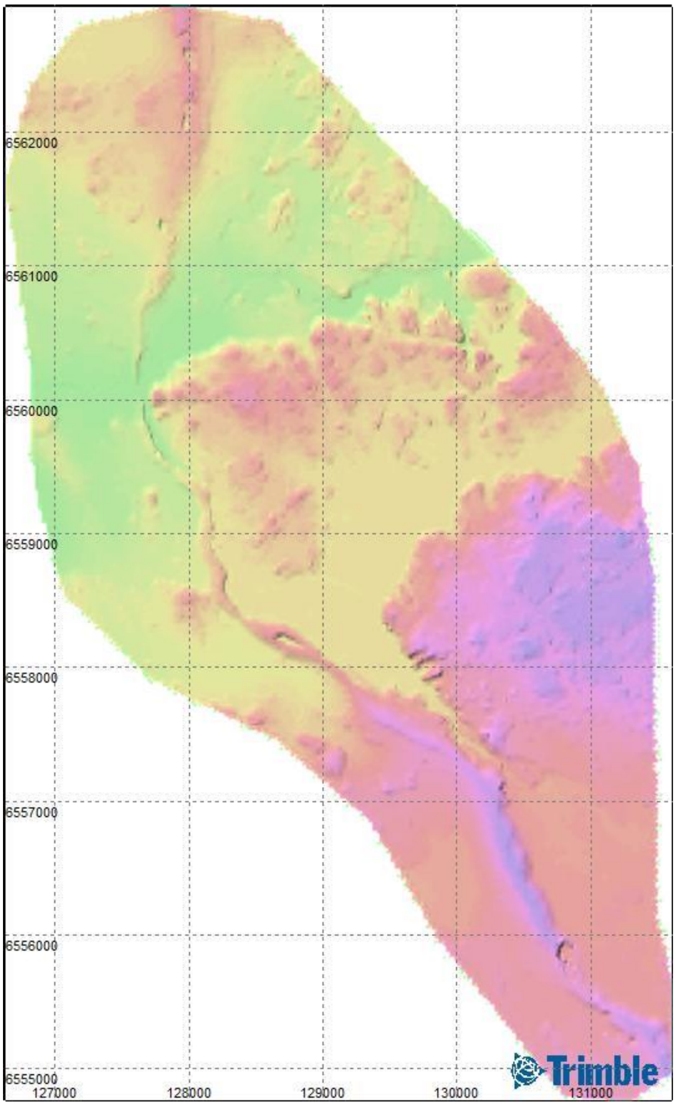


Figure 3.4 Show the digital terrain model used in the study.

3.5.4 Possible geotechnical issues

The identified areas where there are possible geotechnical issues are illustrated in Figure 3.5. In the area west and north of Äs there are large areas of agricultural land, this area may cause geotechnical problems (Trafikverket, 2011 (a)).

This data were given by WSP as an SHP file, when imported into Trimble Quantm the zones where entered as an avoid zone with the status high which means that the program will not enter the zone, if there are no other possibility the program will give a warning that the zone has been entered. The zones are given the status high due to the possible increase of cost when entering the zone.

Figure 3.5 Show the zones where there are possible geotechnical issues.

3.5.5 Cultural environment

The identified areas where there are possible cultural environmental values are illustrated in Figure 3.6. The area around Äs is of national interest for the heritage sectors. Heritage sites are found adjacent to the existing road 56. Within the study area there are also mansions with long avenues together with landscapes that are characterized by agriculture that can be traced back to the middle age. Findings of national interest from the Stone Age together with remains from the bronze and Iron Age can also be found. (Trafikverket, 2011 (a)).

The data on where the possible cultural values are located was provided by WSP in SHP file format. When imported into Trimble Quantm the zones where entered as an avoid zone with the status high with exception for the zone that are in conflict with the finish point. This zone were given the status medium to make it possible to run the model, The status medium means that the program will enter the zone however it will try to do it as little as possible. Since the environmental and geotechnical avoid zones are impossible to not interfere with.

Figure 3.6 Show the zones where there are possible cultural values.

3.5.6 Landscape environment

The identified zones of landscape environmental values within the area are illustrated in Figure 3.7. The area is mainly dominated by forest. Around the town Äs the landscape opens up and small areas of agricultural land mostly with diary farms can be found (Trafikverket, 2011 (a)).

The data on where the possible landscape values are located were provided by WSP as an SHP file. When imported into Trimble Quantm the zones where entered as an avoid zone with the status medium which means that the program will try to avoid the zones as much as possible. The status medium where given due to that the increase of the cost when entering a zone are not as high compared with the cultural and geotechnical zones.

Figure 3.7 Show the zones where there are landscape environmental issues.

3.5.7 Natural environment

The identified areas of natural environmental value within the area are shown in Figure 3.8. The area around the lake Aspen including the inlet in the south are both listed in the natural conservation program. The outlet from the lake is identified as a wetland and a key habitant. There are also several other natural values and swamp forests around the lake (Trafikverket, 2011 (a)).

The data on where the possible natural environmental issues are located were provided by WSP as an SHP file. When imported into Trimble Quantm the zones where entered as an avoid zone with the status medium which means that the program will try to avoid the zones as much as possible. The status medium where given due to that the increase of the cost when entering a zone are not as high compared with the cultural and geotechnical zones.

Figure 3.8 Show the zones where there are natural environmental issues.

3.5.8 Other areas that needs to be avoid

I addition to the possible environmental and geotechnical issues there are other sites within the area that needs to be avoided. The other avoid zones are illustrated in Figure 3.9. The zones are the town Äs, houses located outside the town and the lake Aspen. The houses and the town Äs where identified by studying the satellite photos given by WSP. The houses and the town where given an avoid zone with the high status together with the lake Aspen that also where given a high status due to environmental causes.

Figure 3.9 Shows the avoid zones where there are houses together with the avoid zone for the lake Aspen.

3.5.9 Technical specification for the road

The chapter presents the technical specifications for the new road. The coordinates for the start and finish points for the road can be found in Table 3.5 together with the parameters for the design of the superstructure that are found in Table 3.6.

Table 3.5 Shows the coordinates for the start and finish points for the alignment.

Design speed	100 Km/h (Trafikverket, 2011 (a))		
Total with of the road	12,25 meters (Trafikverket, 2011 (a))		
Minimum horizontal radius	700 meters (Trafikverket, 2012 (a))		
Minimum vertical radius	6000 meters (Trafikverket, 2012 (a))		
Width of the road	12,25 meters (Trafikverket, 2011 (a))		
Start/Finish Points	**Coordinates [X;Y;Z]** (Wettermark, 2013)	**Bearing**	**Grade [%]**
Start	128204.191;6558575.277;56.612	338.1	-2.41
Finish	127987.6;6562417.4;65.027	334.4	-1.78

Table 3.6 Shows the input parameters for the template.

Template			
Left			
With	6,125	m	With of left lane
Thickness	0,5	m	Thickness of pavement left lane (Trafikverket, 2004)
Right			
With	6,125	m	With of right lane
Thickness	0,5	m	Thickness of pavement right lane (Trafikverket, 2004)

3.6 Possible corridors chosen by WSP

There have been four possible corridors chosen by WSP for the new road outside Äs; the corridors are illustrated in Figure 3.10. One of these corridors will be used for the construction of the new road outside the town.

For corridor one, two and three the new road will follow the current route until that one have passed the lake Aspen, thereafter the corridors divides in to three different possible paths for the new road. The first and second corridor passes close to the east side of the town Äs and then merge and follow the current route again, see Figure 3.10. The third corridor turns to the right making a new path for the road within the area of interests, see Figure 3.10. With corridor number four the new road will follow a completely new path for the entire stretch, the corridor passes on the east side of the lake Aspen and then merge with the third corridor to connect to the current route in the end of the area of interest, which can be seen in Figure 3.10.

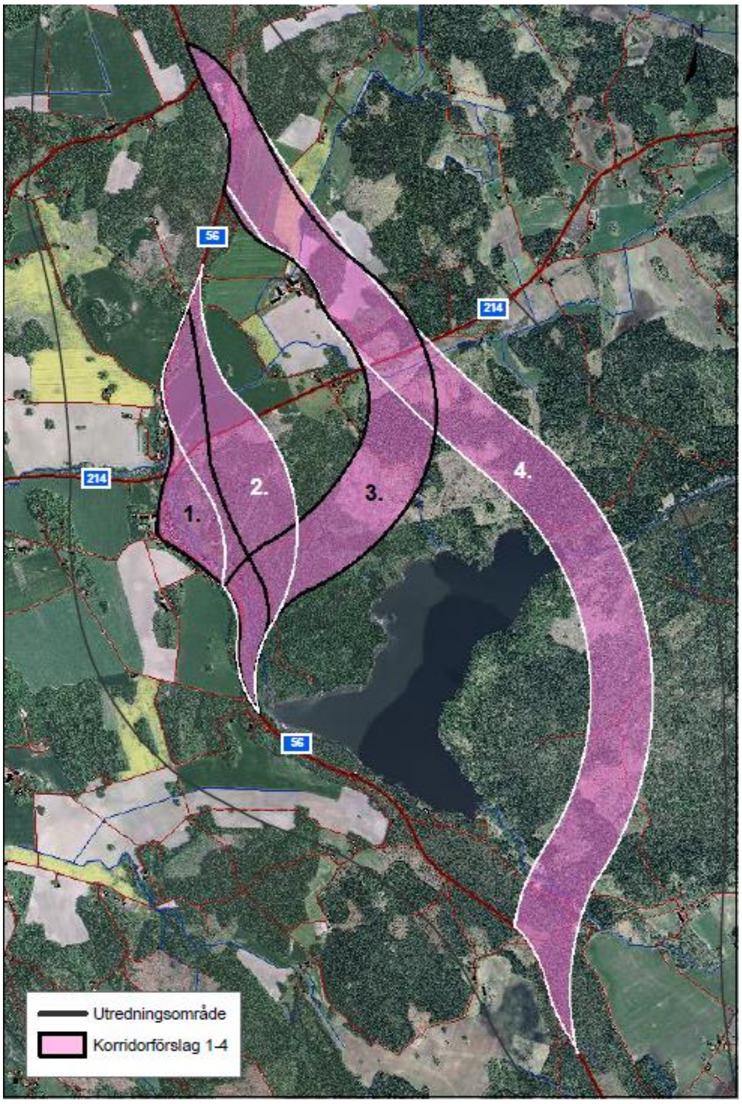


Figure 3.10 Illustrate path for the four corridors given by WSP.

4 Results

This chapter presents the results from the case study which includes the corridors generated by Trimble Quantm, the optimized alignment within the corridors and the intrusion in environmental and geotechnical zones. The chapter also presents the results of the optimized alignments within the corridors given by WSP.

4.1 Corridor generated by Quantm

The software identified one corridor that runs to the west of lake Aspen close outside the town Äs. The corridor is shown in Figure 4.1.

Figure 4.1 Shows the corridors generated by Trimble Quantm.

4.2 Intrusion in environmental and geotechnical zones

The chapter presents the results of the possible impact to the environmental and geotechnical zones for each corridor generated by Trimble Quantm and the corridors given by WSP.

4.2.1 For corridors given by WSP

Corridor 1

The result for the intrusion in environmental and geotechnical zones generated by corridor 1 is shown in Figure 4.2. The results of the area in square meters that are affected by the corridor and the predicted extra costs associated with each zone are shown in Figure 4.3.

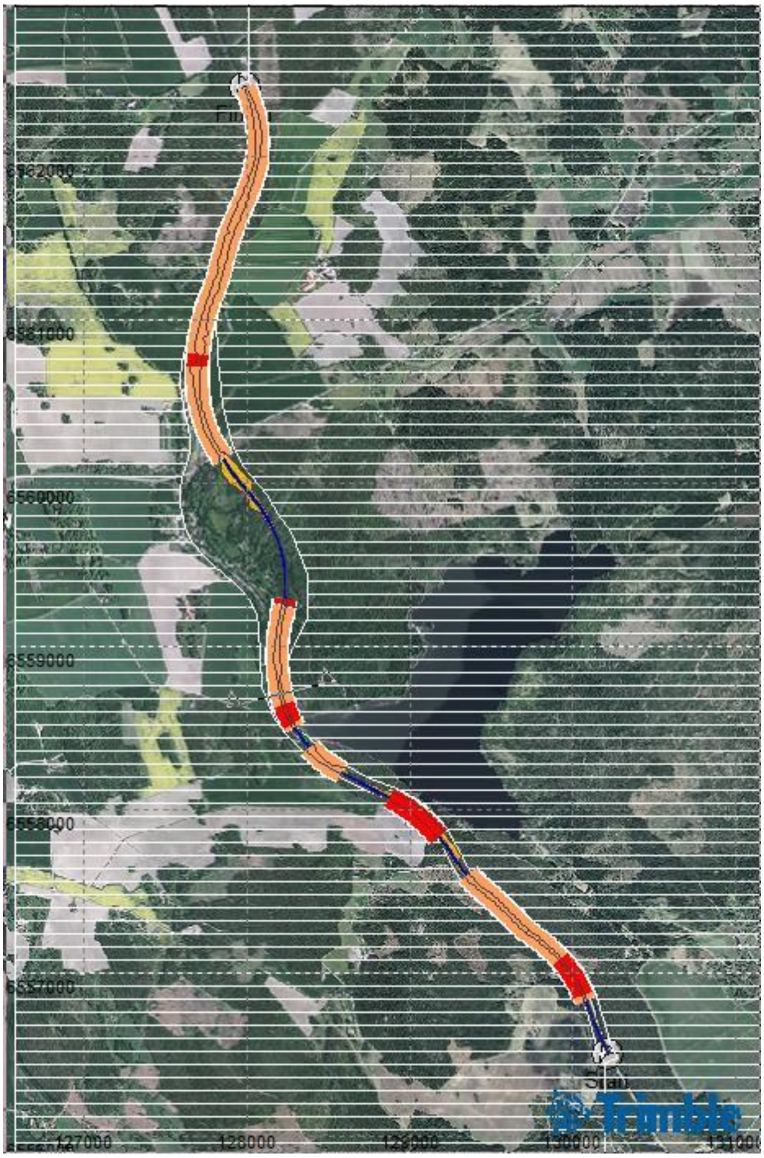


Figure 4.2 Shows where corridor 1 passes thru zones with environmental or geotechnical issues.

Area Cost Report

N	Name	Type	Area	$
1	Cultural	Footprint	99 900	2 000 000
2	Geotechnical	Footprint	14 200	427 000
3	Natural	Footprint	26 100	130 000
4	Landscape	Footprint	43 400	217 000

Figure 4.3 Shows the area and the extra cost associated with each zone for corridor 1.

Corridor 2

The result for the intrusion in environmental and geotechnical zones generated by corridor 2 is shown in Figure 4.4. The results of the area in square meters that are affected by the corridor and the predicted extra costs associated with each zone are shown in Figure 4.5.

Figure 4.4 Shows where corridor 2 passes thru zones with environmental or geotechnical issues

Area Cost Report

N	Name	Type	Area	$
1	Cultural	Footprint	112 000	2 250 000
2	Geotechnical	Footprint	13 900	418 000
3	Landscape	Footprint	51 400	257 000
4	Natural	Footprint	2 230	11 200

Figure 4.5 Shows the area and the extra cost associated with each zone for corridor 2

Corridor 3

The result for the intrusion in environmental and geotechnical zones generated by corridor 3 is shown in Figure 4.6. The results of the area in square meters that are affected by the corridor and the predicted extra costs associated with each zone are shown in Figure 4.7.

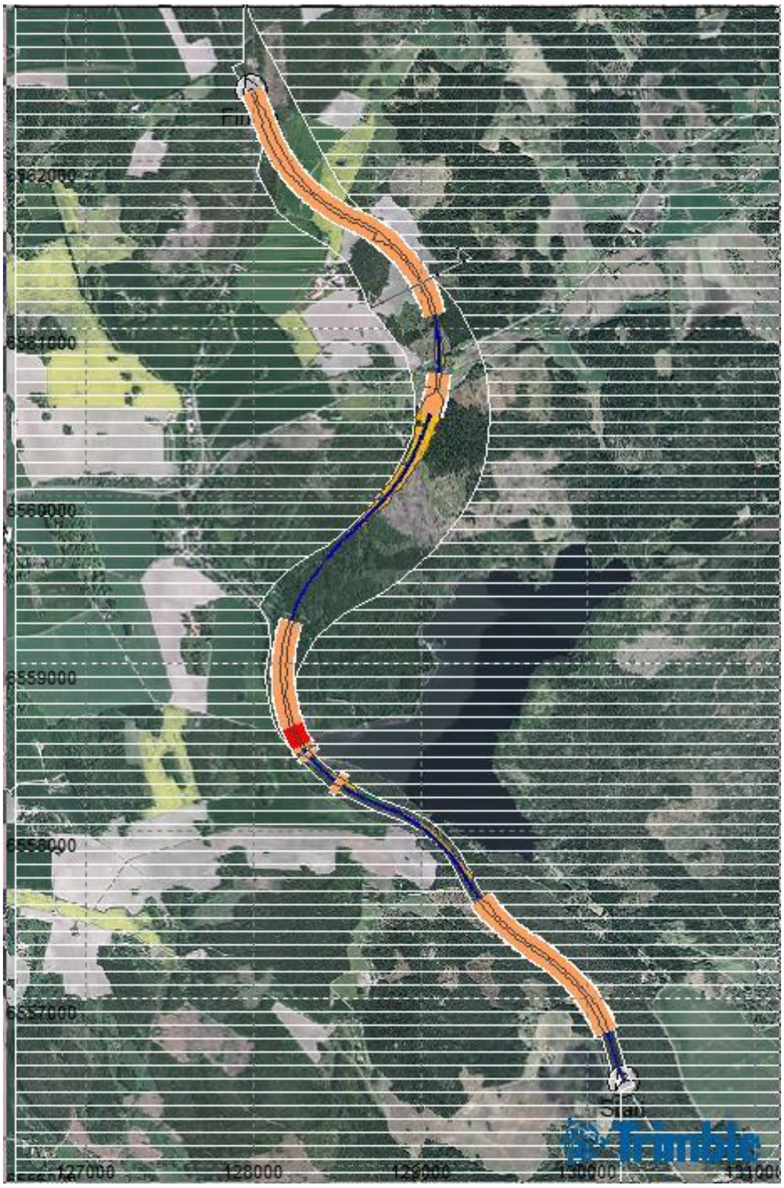


Figure 4.6 Shows where corridor 3 passes thru zones with environmental or geotechnical issues.

Area Cost Report

N	Name	Type	Area	$
1	Cultural	Footprint	79 300	1 590 000
2	Geotechnical	Footprint	35 200	1 050 000
3	Natural	Footprint	25 200	126 000
4	Landscape	Footprint	36 900	185 000

Figure 4.7 Shows the area and the extra cost associated with each zone for corridor 3.

Corridor 4

The result for the intrusion in environmental and geotechnical zones generated by corridor 4 is shown in Figure 4.8. The results of the environmental and geotechnical areas in square meters affected by corridor 4 and the predicted extra costs associated with each zone are shown in Figure 4.9.

Figure 4.8 *Shows where corridor 4 passes thru zones with environmental or geotechnical issues.*

Area Cost Report

N	Name	Type	Area	$
1	Cultural	Footprint	123 000	2 470 000
2	Natural	Footprint	31 900	159 000
3	Landscape	Footprint	35 800	179 000
4	Geotechnical	Footprint	31 600	949 000

Figure 4.9 *Shows the area and the extra cost associated with each zone for corridor 4.*

4.2.2 For corridor generated by Quantm

Corridor Q1

The result for the intrusion in environmental and geotechnical zones generated by corridor Q1 is shown in Figure 4.10. The results of the environmental and geotechnical areas in square meters affected by corridor 4 and the predicted extra costs associated with each zone are shown in Figure 4.11.

Figure 4.10 Shows where corridor Q1 passes thru zones with environmental or geotechnical issues.

Area Cost Report

N	Name	Type	Area	$
1	Cultural	Footprint	74 400	1 490 000
2	Geotechnical	Footprint	47 300	1 420 000
3	Natural	Footprint	14 200	71 200
4	Landscape	Footprint	37 600	188 000

Figure 4.11 Shows the area and the extra cost associated with each zone for corridor Q1.

4.3 Optimized alignment for each corridor

The chapter presents the optimized alignments for the corridor provided by WSP along with the corridor generated by Trimble Quantm.

4.3.1 For corridors given by WSP

Corridor 1

The results for the optimised alignment generated by Trimble Quantm for WSP corridor number 1. The alignment in plan is illustrated in Figure 4.12 and the alignment in profile is illustrated in Figure 4.13. A detailed summary of the alignment which shows the quantity and cost for the activities associated with the alignment can be found in Figure 4.14. An illustration of how the alignment is affected by the avoid zones of environmental value, other avoid zones and geotechnical issues, see Appendix A.

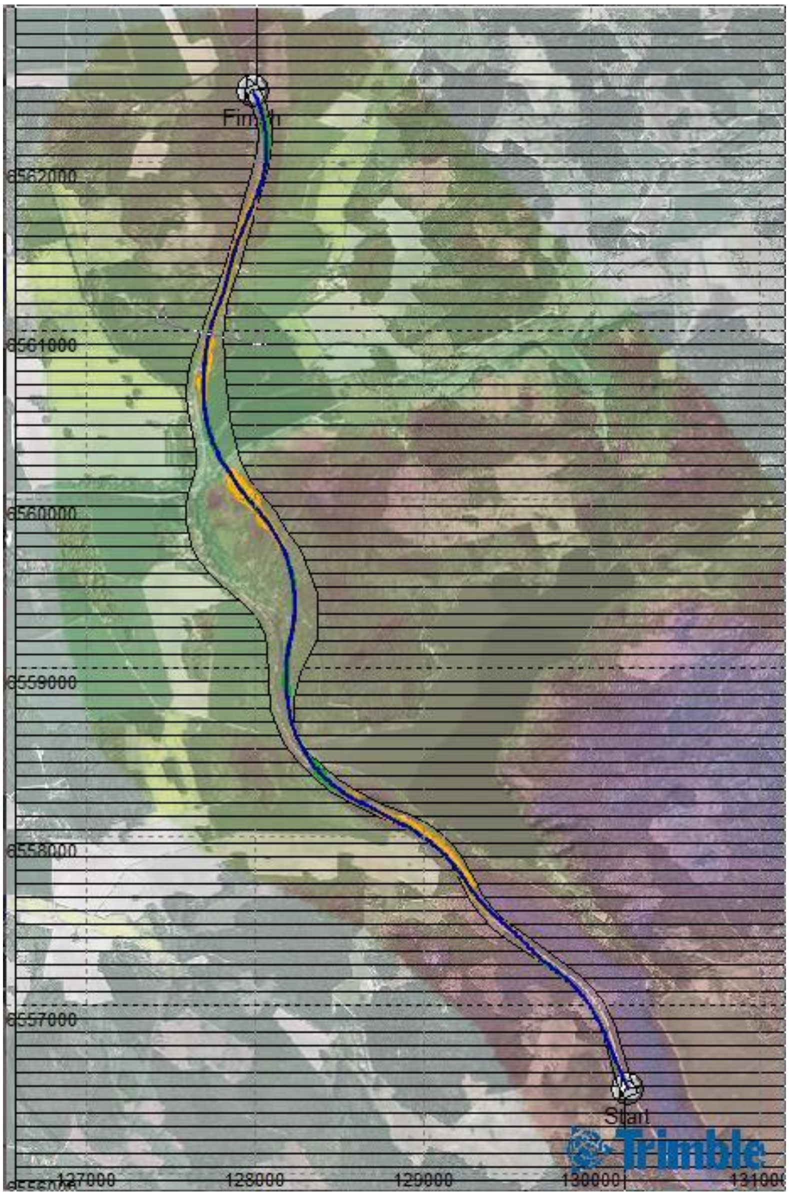


Figure 4.12 Shows the optimal alignment for corridor 1 generated by Trimble Quantm.

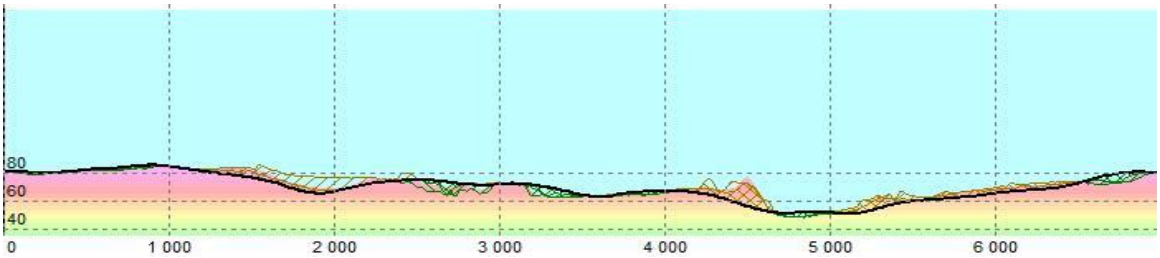
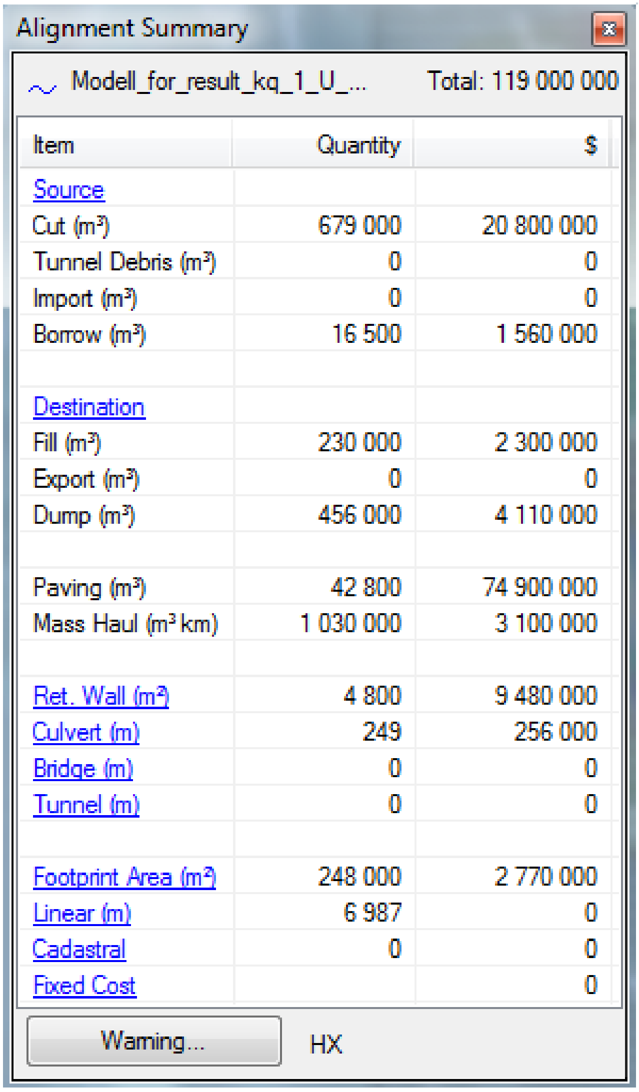


Figure 4.13 Shows the optimal alignment in profile for corridor 1.



Alignment Summary

Modell_for_result_kq_1_U_... Total: 119 000 000

Item	Quantity	$
Source		
Cut (m³)	679 000	20 800 000
Tunnel Debris (m³)	0	0
Import (m³)	0	0
Borrow (m³)	16 500	1 560 000
Destination		
Fill (m³)	230 000	2 300 000
Export (m³)	0	0
Dump (m³)	456 000	4 110 000
Paving (m³)	42 800	74 900 000
Mass Haul (m³ km)	1 030 000	3 100 000
Ret. Wall (m²)	4 800	9 480 000
Culvert (m)	249	256 000
Bridge (m)	0	0
Tunnel (m)	0	0
Footprint Area (m²)	248 000	2 770 000
Linear (m)	6 987	0
Cadastral	0	0
Fixed Cost		0

Warning... HX

Figure 4.14 Shows the summary of the activities associated with the optimized alignment in corridor 1.

Corridor 2

The results for the optimised alignment generated by Trimble Quantm for WSP corridor number 2. The alignment in plan is illustrated in Figure 4.15 and the alignment in profile is illustrated in Figure 4.16. A detailed summary of the alignment which shows the quantity and cost for the activities associated with the alignment can be found in Figure 4.17). An illustration of how the alignment is affected by the avoid zones of environmental value, other avoid zones and geotechnical issues, see Appendix A.

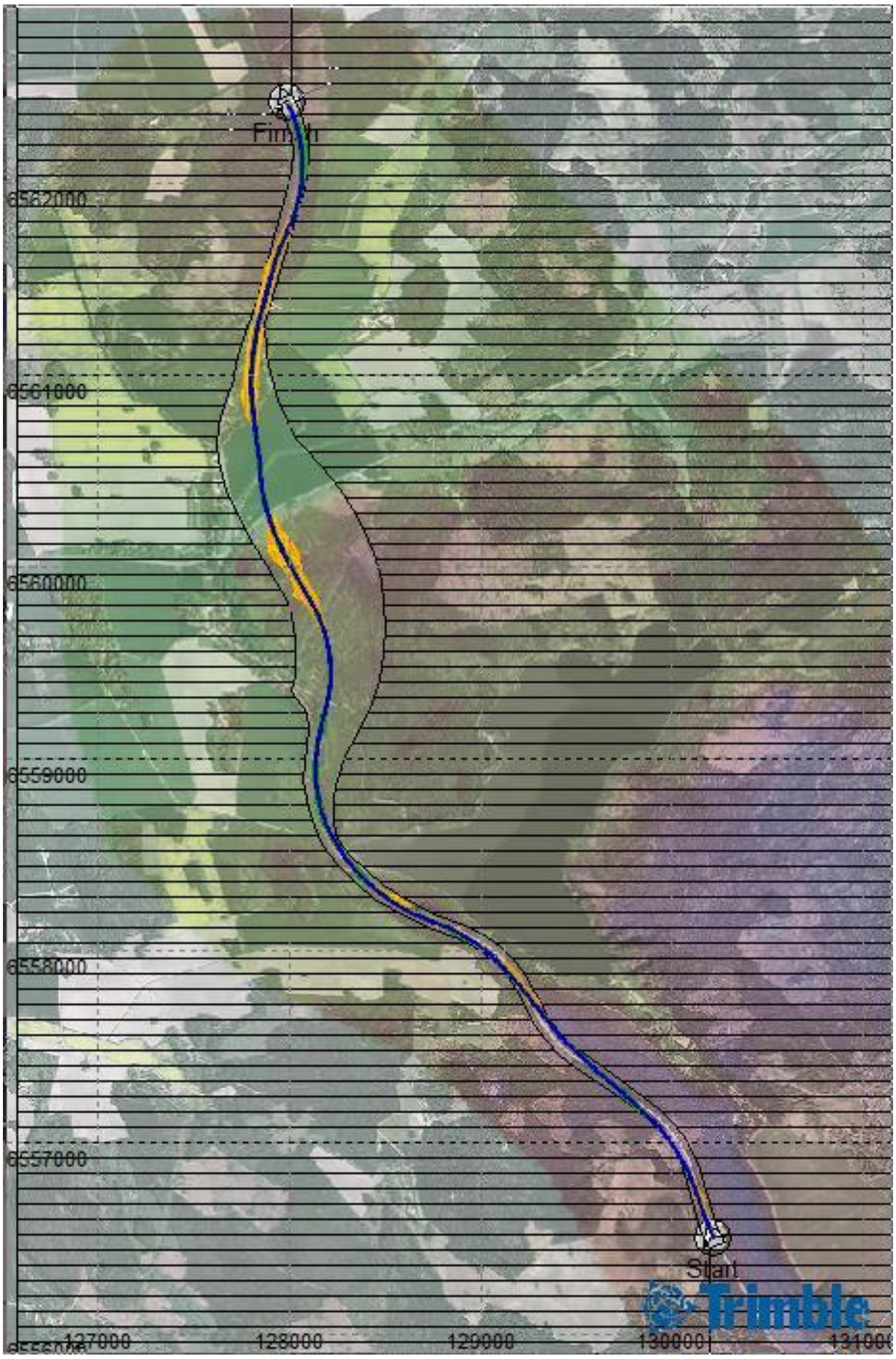


Figure 4.15 Shows the optimal alignment for corridor 2 generated by Trimble Quantm.

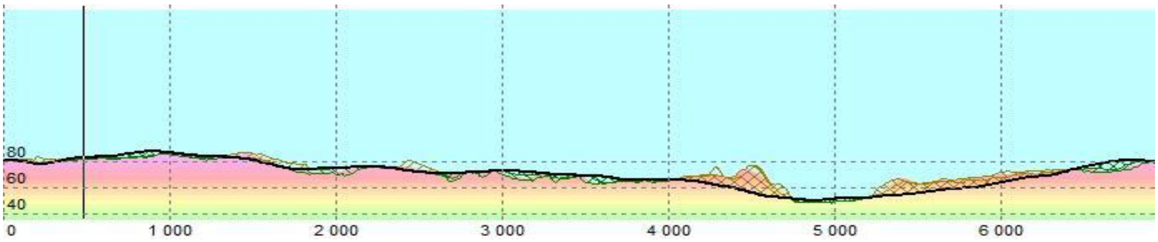


Figure 4.16 *Shows the optimal alignment in profile for corridor 2.*

Alignment Summary

Modell_for_result_kq_1_1_... Total: 120 000 000

Item	Quantity	$
Source		
Cut (m³)	774 000	25 000 000
Tunnel Debris (m³)	0	0
Import (m³)	0	0
Borrow (m³)	1 540	144 000
Destination		
Fill (m³)	272 000	2 720 000
Export (m³)	0	0
Dump (m³)	493 000	4 440 000
Paving (m³)	42 500	74 300 000
Mass Haul (m³ km)	1 300 000	3 910 000
Ret. Wall (m²)	3 390	6 700 000
Culvert (m)	120	125 000
Bridge (m)	0	0
Tunnel (m)	0	0
Footprint Area (m²)	251 000	2 930 000
Linear (m)	6 933	0
Cadastral	0	0
Fixed Cost		0

Warning... HX

Figure 4.17 *Shows the summary of the activities associated with the optimized alignment in corridor 2.*

Corridor 3

The results for the optimised alignment generated by Trimble Quantm for WSP corridor number 3. The alignment in plan is illustrated in Figure 4.18 and the alignment in profile is illustrated in Figure 4.19. A detailed summary of the alignment which shows the quantity and cost for the activities associated with the alignment can be found in Figure 4.20. An illustration of how the alignment is affected by the avoid zones of environmental value, other avoid zones and geotechnical issues, see Appendix A.

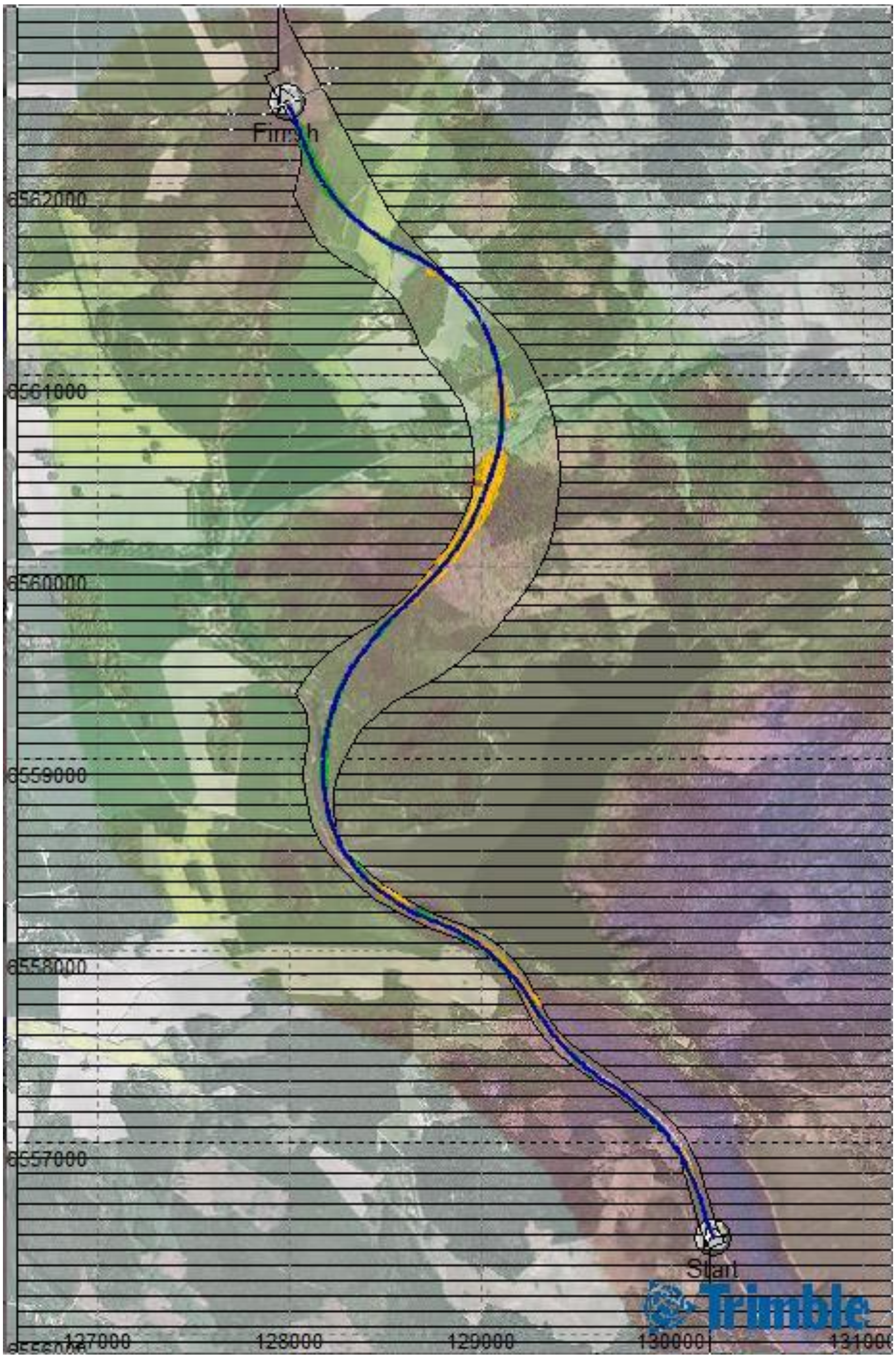


Figure 4.18 Shows the optimal alignment for corridor 3 generated by Trimble Quantm.

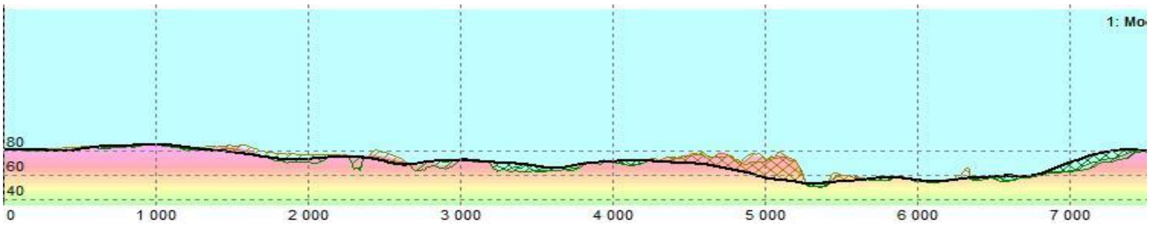
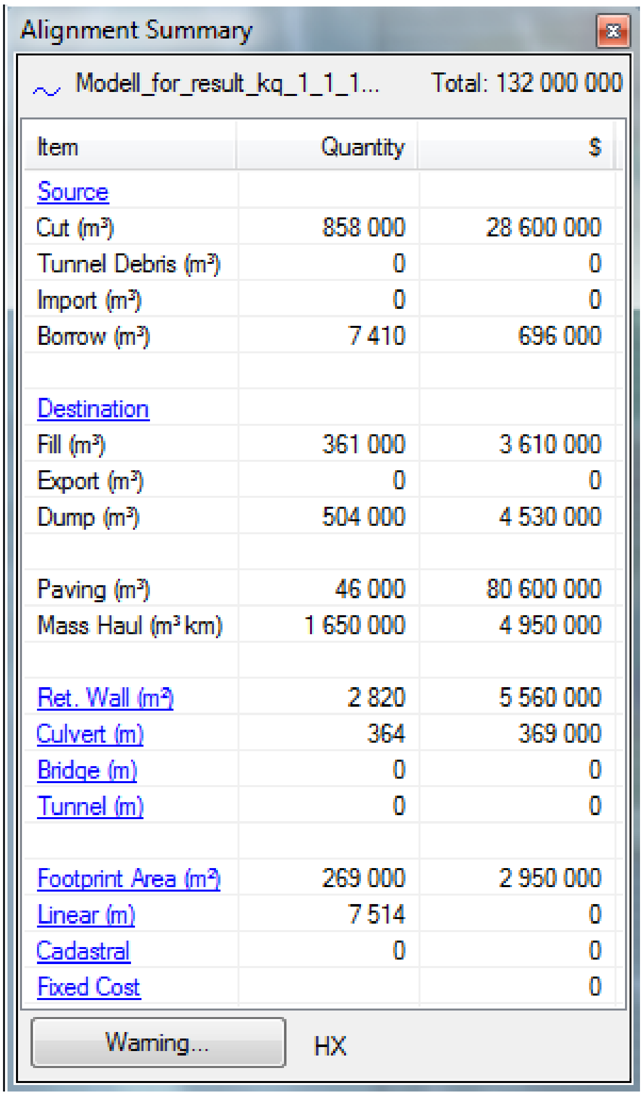


Figure 4.19 *Shows the optimal alignment in profile for corridor 3.*



Alignment Summary

Modell_for_result_kq_1_1_1... Total: 132 000 000

Item	Quantity	$
Source		
Cut (m³)	858 000	28 600 000
Tunnel Debris (m³)	0	0
Import (m³)	0	0
Borrow (m³)	7 410	696 000
Destination		
Fill (m³)	361 000	3 610 000
Export (m³)	0	0
Dump (m³)	504 000	4 530 000
Paving (m³)	46 000	80 600 000
Mass Haul (m³ km)	1 650 000	4 950 000
Ret. Wall (m²)	2 820	5 560 000
Culvert (m)	364	369 000
Bridge (m)	0	0
Tunnel (m)	0	0
Footprint Area (m²)	269 000	2 950 000
Linear (m)	7 514	0
Cadastral	0	0
Fixed Cost		0

Warning... HX

Figure 4.20 *Shows the summary of the activities associated with the optimized alignment in corridor 3.*

Corridor 4

The results for the optimised alignment generated by Trimble Quantm for WSP corridor number 4. The alignment in plan is illustrated in Figure 4.21 and the alignment in profile is illustrated in Figure 4.22. A detailed summary of the alignment which shows the quantity and cost for the activities associated with the alignment can be found in Figure 4.23. An illustration of how the alignment is affected by the avoid zones of environmental value, other avoid zones and geotechnical issues, see Appendix A).

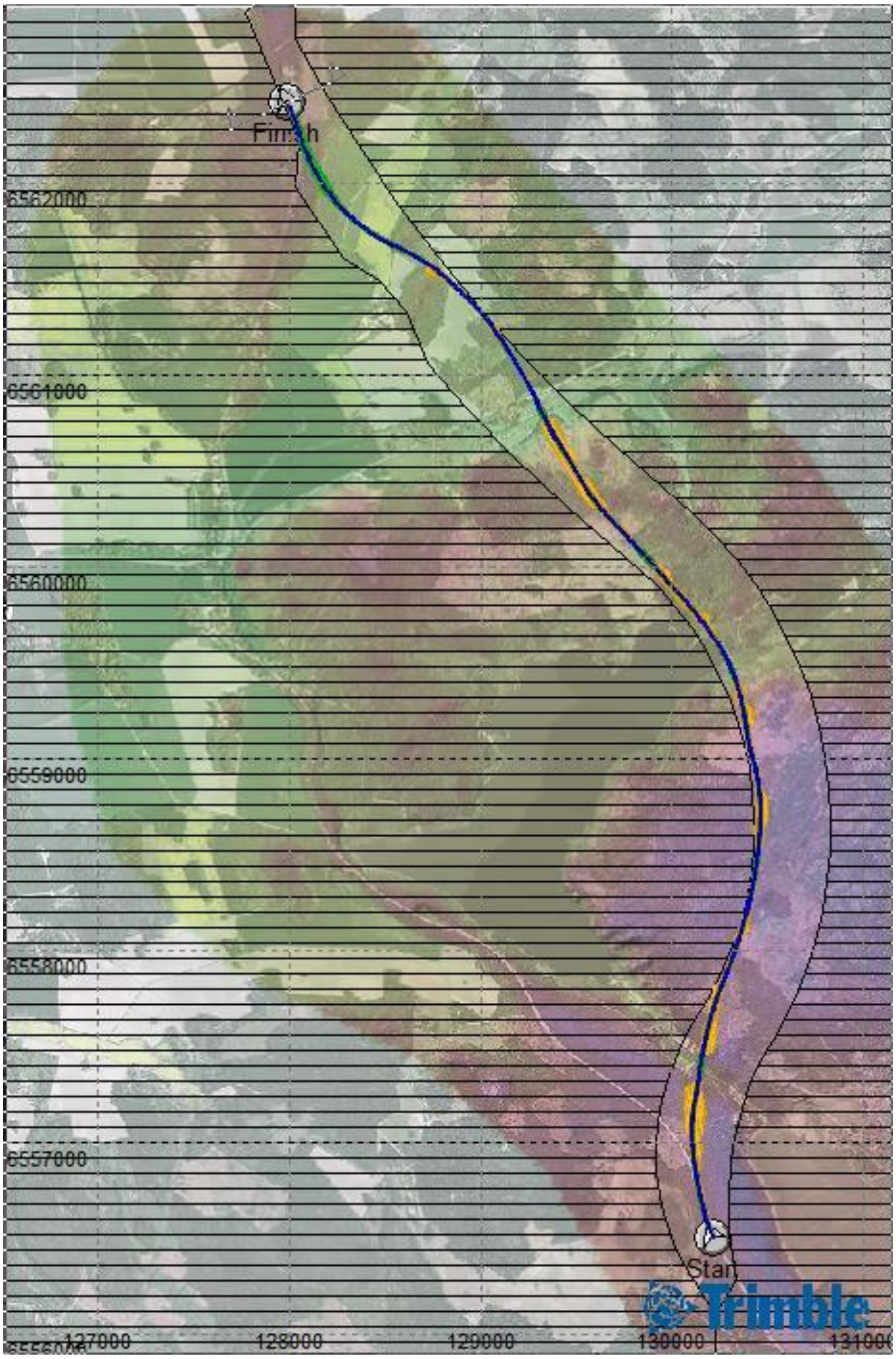


Figure 4.21 Shows the optimal alignment for corridor 4 generated by Trimble Quantm.

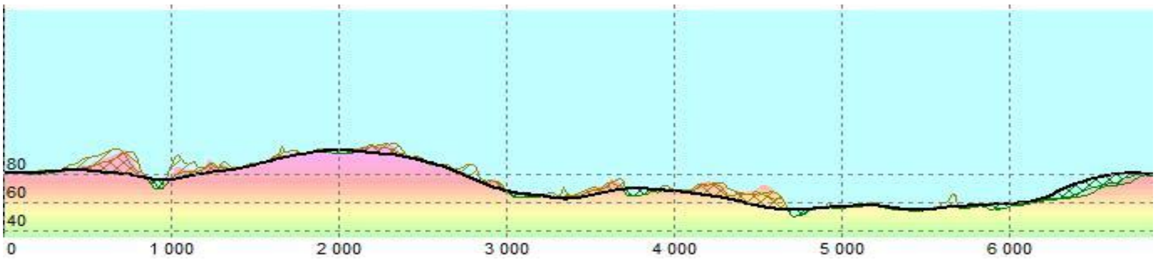
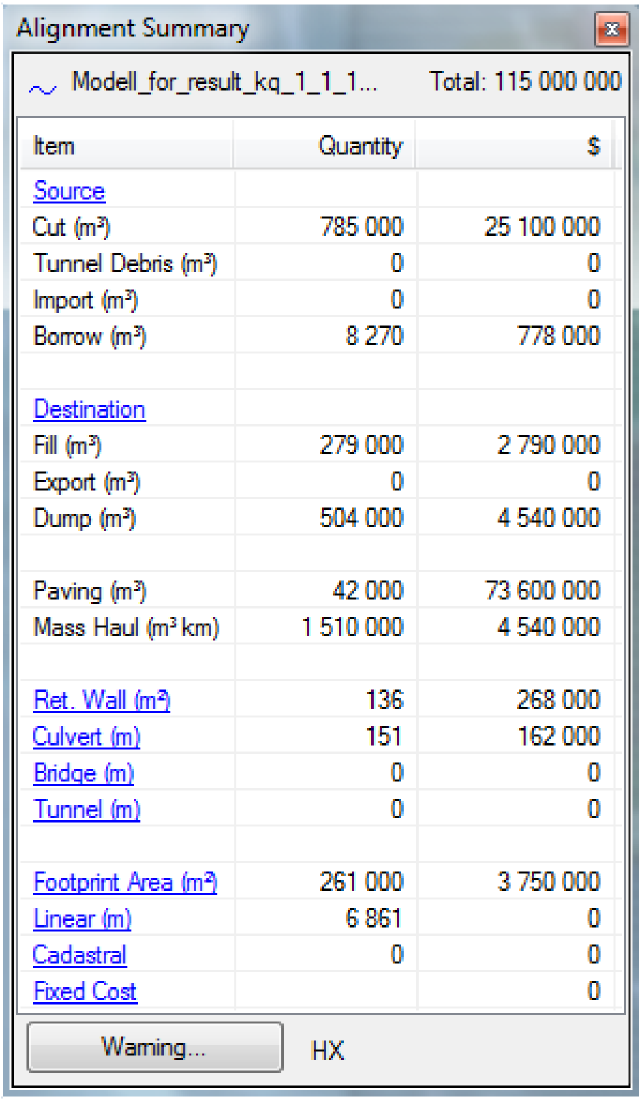


Figure 4.22 *Shows the optimal alignment in profile for corridor 4.*


Alignment Summary

Modell_for_result_kq_1_1_1... Total: 115 000 000

Item	Quantity	$
Source		
Cut (m³)	785 000	25 100 000
Tunnel Debris (m³)	0	0
Import (m³)	0	0
Borrow (m³)	8 270	778 000
Destination		
Fill (m³)	279 000	2 790 000
Export (m³)	0	0
Dump (m³)	504 000	4 540 000
Paving (m³)	42 000	73 600 000
Mass Haul (m³ km)	1 510 000	4 540 000
Ret. Wall (m²)	136	268 000
Culvert (m)	151	162 000
Bridge (m)	0	0
Tunnel (m)	0	0
Footprint Area (m²)	261 000	3 750 000
Linear (m)	6 861	0
Cadastral	0	0
Fixed Cost		0

Warning... HX

Figure 4.23 *Shows the summary of the activities associated with the optimized alignment in corridor 4.*

4.3.2 For corridor generated by Quantm

Corridor Q1

The results for the optimised alignment generated by Trimble Quantm for corridor Q1. The alignment in plan is illustrated in Figure 4.24 and the alignment in profile is illustrated in Figure 4.25. A detailed summary of the alignment which shows the quantity and cost for the activities associated with the alignment can be found in Figure 4.26. An illustration of how the alignment is affected by the avoid zones of environmental value, other avoid zones and geotechnical issues, see Appendix A. An illustration of the alignment together with all corridors can be found in Appendix B.

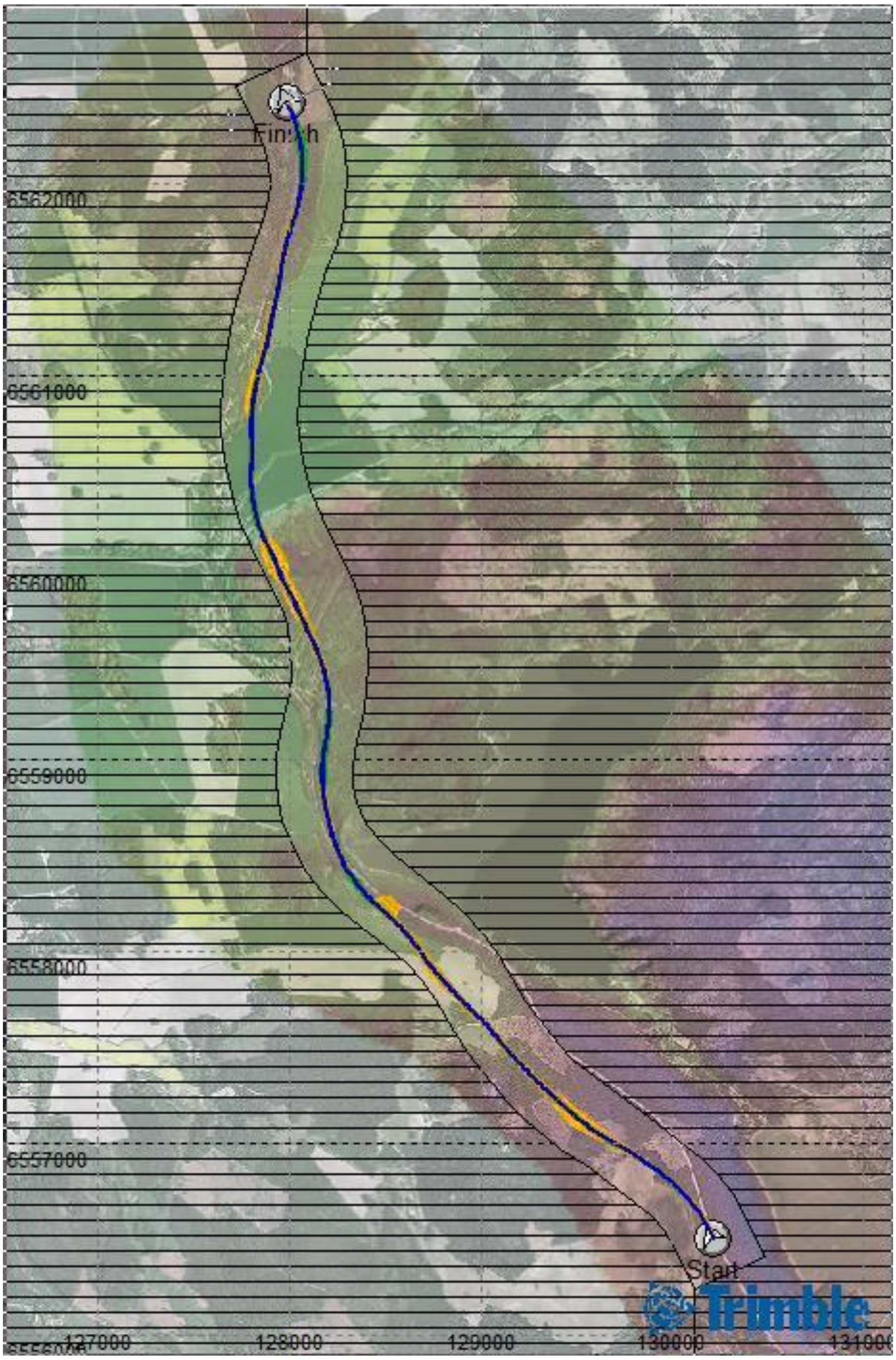


Figure 4.24 Shows the optimal alignment for corridor Q1 generated by Trimble Quantm.

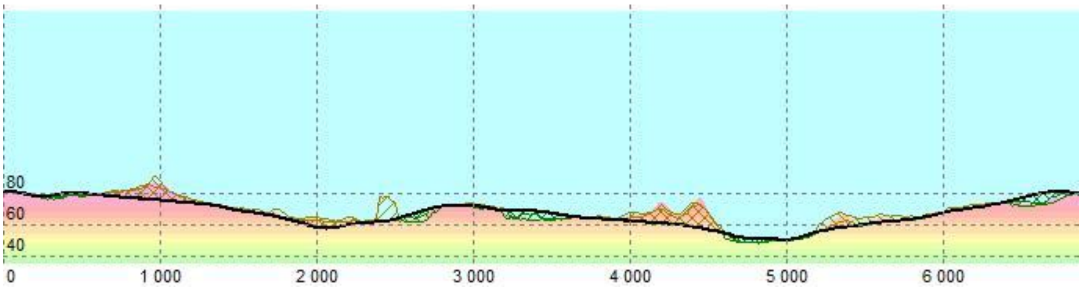
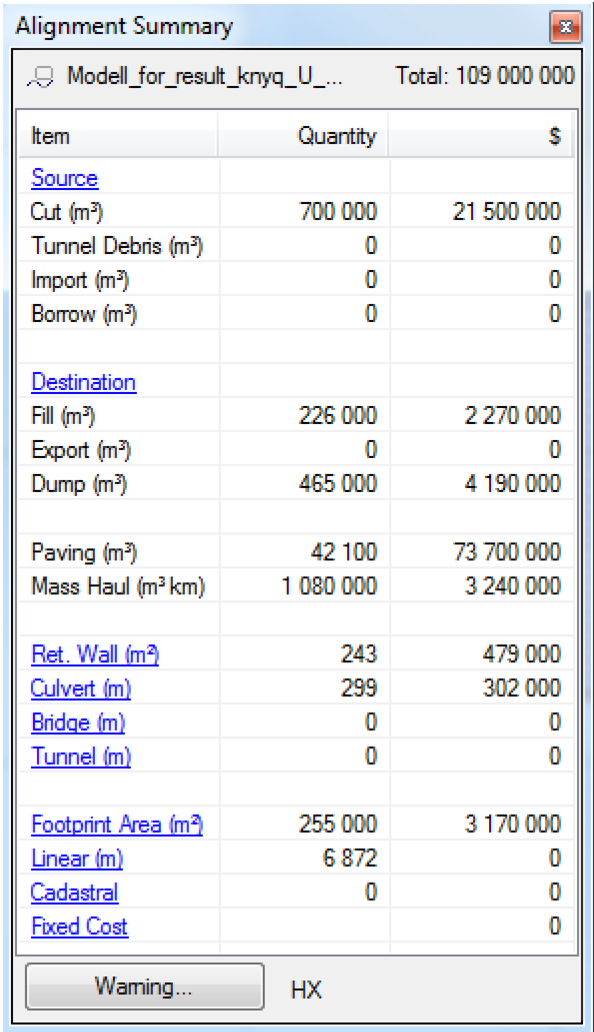


Figure 4.25 Shows the optimal alignment in profile for corridor Q1.



Alignment Summary

Modell_for_result_knyq_U_... Total: 109 000 000

Item	Quantity	$
Source		
Cut (m³)	700 000	21 500 000
Tunnel Debris (m³)	0	0
Import (m³)	0	0
Borrow (m³)	0	0
Destination		
Fill (m³)	226 000	2 270 000
Export (m³)	0	0
Dump (m³)	465 000	4 190 000
Paving (m³)	42 100	73 700 000
Mass Haul (m³ km)	1 080 000	3 240 000
Ret. Wall (m²)	243	479 000
Culvert (m)	299	302 000
Bridge (m)	0	0
Tunnel (m)	0	0
Footprint Area (m²)	255 000	3 170 000
Linear (m)	6 872	0
Cadastral	0	0
Fixed Cost		0

Warning... HX

Figure 4.26 Shows the summary of the activities associated with the optimized alignment in corridor Q1.

4.4 Summary of result for all corridors

All investigated corridors are illustrated in Figure 4.27. Corridors 1-4 are the corridors given by WSP and corridor Q1 is the corridor generated by Trimble Quantm. A summary of the costs and quantity for each of the possible issue zones are shown in Table 4.1. The total costs for the possible issue zones and the total construction cost for each alignment can be found in Table 4.2.

Table 4.1 Shows a summary for the costs and areas for the possible issues relating to the optimized alignment for each corridor.

	Environmental issues				**Geotechnical issues**	
Corridor	**Cultural-cost [kkr]**	**Natural-cost [kkr]**	**Landscape-cost [kkr]**	**Quantity [m^2]**	**Cost [kkr]**	**Quantity [m^2]**
1	2000	130	217	169,4	427	14,2
2	2250	**11,2**	257	165,63	**418**	**13,9**
3	1590	126	185	141,4	1050	35,2
4	2470	159	**179**	190,7	949	31,6
Q1	**1490**	71,2	188	**126,2**	1420	47,3

Table 4.2 Shows the area affected by the alignment together with the total cost for the road and the issue zones.

Corridor	**Total quantity of issue zones [m^2]**	**Total cost for possible issues [kkr]**	**Total cost [kkr]**
1	**248**	**2770**	119000
2	251	2930	120000
3	269	2950	132000
4	261	3750	115000
Q1	255	3170	**109000**

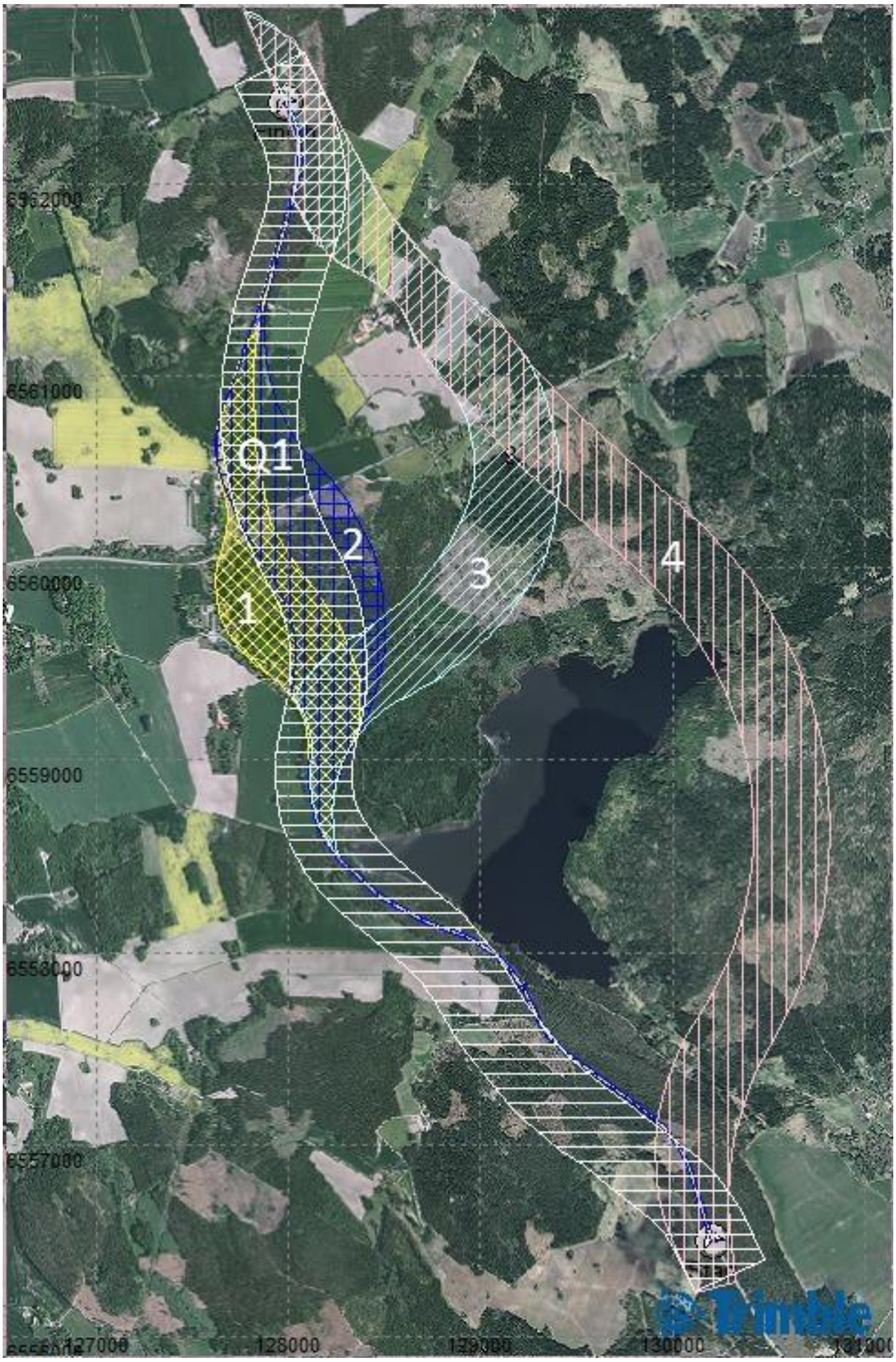


Figure 4.27 Shows WSP corridors 1-4 and corridor Q1 generated by Trimble Quantm.

5 Discussion

The software Trimble Quantm is an alignment optimization program that will find and create the optimal alignment between two points taking all requirements into account. The chapters below will discuss the results of the case study and the usability of the software.

5.1 Corridor generated by Quantm

The software generates a corridor west of the lake Aspen and east of the town Äs. The corridor almost follows the path of the existing road until it reaches the end of the lake. Thereafter it turns to the right and creates a new path east of the town and continues to the finish point. According to the software, this corridor contains the optimal alignment for the proposed new road based on the avoid zones and costs entered. The corridor has almost the same path as for WSP corridor 1 and 2, with the exception of the beginning of the corridor. The beginning of the corridor runs left of the existing road 56 until it reaches the lake Äs where it merges with WSP corridor 1 and 2. The reason that the corridor runs to the left in the beginning is probably due to the cultural value zone located to the right near the starting point. The corridor then follows the same route as for WSP corridors 1 and 2 indicating that the most advantageous alignment could be within these three corridors.

5.2 Intrusion in environmental and geotechnical zones

The result shows that it is impossible to find an alignment that is not in conflict with any of the environmental values or the possible geotechnical issues zones since most of the zones overlap. The identified areas of geotechnical problems usually increase the construction cost for the road the most, while the impact in environmental can affect the cost more or less since they have different conservation values (Wettermark, 2013). The software compares the cost of entering an issue zone to the cost of avoiding it, and suggests the most cost efficient alternative.

The results of the impact in environmental value zones and the possible geotechnical issues zones for the corridors 1 and 2 shows that the impact in the cultural zones is the greatest. Since the corridors follow the path of the existing road where the cultural zones are located, the costs for entering will probably be lower. The values are possibly already ruined in these parts when the existing road were built (Trafikverket, 2011 (a)). Since the cultural values are one of the cost parameters that affect the total construction cost the most, the cost for the construction in these corridors will probably be lower than calculated. For corridor 3 the first part of the corridor follows the same route as for corridor 1 and 2 which would mean that the cost for the cultural value will be lower than calculated for this corridor as well. The result for corridor 3 shows that it interferes with a large area of possible geotechnical issues. The aforementioned could mean that there is an uncertainty in the total construction cost for the corridor as more or less reinforcement measures may be needed in these sections (Trafikverket, 2011 (a)). The path of corridor 4 mostly interferes with areas including cultural values. In addition, the corridor affects approximately the same amount of possible geotechnical zones, landscape value and natural values. The estimated costs for this corridor are probably more reliable than for the other corridors, since there is no usage of the existing road.

For corridor Q1 generated by Quantm the intrusion in cultural values zones are lower than in the corridors given by WSP. The affected area is 74400 m^2, approximately the same as for corridor 3 and between 25000 m^2 to 50000 m^2 less than for corridor 1, 2 and 4. However the intrusion in the possible geotechnical issue zones is the highest of the alternatives, almost 15000 m^2 more than for corridors 3 and 4 and approximately 30000 m^2 more than for corridor 1 and 2. A reason why more geotechnical issue zones are affected is probably a consequence of the alignment within the corridor will be shorter, which compensates for the extra costs of entering the geotechnical zone instead of the cultural zone. The affected area of possible natural value is approximately 50000 m^2 more for corridor Q1 than for all the corridors suggested by WSP. That is due to the fact that the corridor needs to enter the natural zone in order to fulfil the restrictions on the minimum radius set by the Swedish traffic authority (Trafikverket, 2012 (a)). The affected landscape area are about the same for corridor Q1 as for corridors 3 and 4, and approximately 60000 m^2 lower than for corridor 1 and 2.

Common for all corridors is that the result shows an effect on the environmental values. There are however ways of minimizing the effect on the values. The impact on the natural values can be reduced by creating new areas to compensate for the affected ones. The landscape values can be compensated for example by planting new trees and try to make the new road to blend in with the landscape as much as possible (Wettermark, 2013) (Vägverket, 2004). Common for all corridors is that extra caution needs to be taken where there are cultural values, since they are impossible to replace. If a cultural remaining interferes with the suggested path of the new road, there needs to be consultations with experts in the field. To reduce the effect on the values, the expert can decide if a remaining can be seen as less important and could perhaps therefore be moved to another location or be destroyed. The measure of destroying the cultural value should only be used when there is no other option. Even in the case when the value can be seen as less important today, it might be considered important in the future. The aim should be to move the cultural values instead of destroying them when there are no other options (Wettermark, 2013).

5.3 Optimized alignment for each corridor

The alignment within the corridor is much depending on the status given to the zones of environmental or geotechnical issues. If the priority of a zone is high the program is not allowed to enter the zone. If the priority is changed to medium the program will try to avoid the zone as much as possible but are allowed to enter the zone (Trimble, 2012).

The alignment for corridor 1 follows the existing road until it has past the lake Aspen. Although it follows the path of the existing road, the software still calculates as if a new road were built. This means that the cost calculations suggested by the software might be higher than the actual cost for the construction, as costs for entering environmental zones are already taken in the building of the current road (Trafikverket, 2011 (a)). The alignment turns to the right and follows close to the left border of the natural avoid zone trying to run between the natural zone and the avoid zone for the town Äs. After passing these zones the alignment turns to the left through a cut. After the cut the alignment runs forward and merges with the path of the existing road. The result shows that the length of the alignment is 6987 meters. The cost for the construction is held down due to the large cut, which provides material for the construction meaning that only a small amount of material needs to be imported from an external source. The result shows that the cut is the most expensive post besides the paving. Since the need of importing material is low the cost for the cut seams justified along with the costs for transport of material within the target area. The cost of the retaining walls for the alignment is one of the largest posts in the construction cost calculation. The case study shows that the amount of retaining walls is connected with how close the alignment passes an environmental-, geotechnical or another avoid zones. Most of the retaining walls are placed in the beginning of the alignment indicating that the costs will be lower than calculated since only a reconstruction of the current road will be done in these parts. The reason why there are a lot of retaining walls in the beginning is that the corridor is narrow, making the software use retaining walls in order to prevent the road structure from falling outside the corridor (Trimble, 2012).

The alignment for corridor 2 follows the same route as corridor 1 until it has past the lake Aspen. Like the alignment in corridor 1 it turns to the right and follows close to the left border of the natural avoid zone trying to run between the natural zone and the avoid zone for the town Äs. The alignment then turns to the left trying to go as straight as possible towards the end of the wider part in the corridor, only making a small turn to avoid the natural value zone before merging with the path of the existing road. The cuts in this alignment produces more material than in alignment 1, leading to a higher cost for the procedure. Even though more material can be used from this cut compared to the cut in corridor 1, the alignment does not fulfil complete mass balance and material needs to be imported. However the result shows that the amount of imported material is lower than for alignment 1. The costs for the retaining walls are high but will probably lower due to the same reasons as for alignment 1. The length of the alignment is 6933 meters which is shorter than the alignment in corridor 1, still the result shows that the total cost of the construction is one million higher than for alignment 1. This depends on that more zones of environmental values or possible geotechnical issues are affected, in addition there are more cuts but still material needs to be imported.

The alignment for corridor 3 has the same conditions as the alignments in corridor 1 and 2 until it has past the lake Aspen, where it turns more to the right followed by a left turn ending with a turn to the right making a completely new path for the road all the way to the finish point. The alignment tries to keep as much to the inner curve as possible while still fulfilling the restrictions of the minimum curve radius. The result shows that the costs for the cut is higher than for alignment 1 and 2, still the need of importing material is greater than for alignment 2 leading to an increase of the total cost. The costs are also a result of the alignment's length which is 7514 meters, about 500 meters longer than for alignment 1 and 2, depending on the corridor making a wider turn.

The alignment for corridor 4 follows a completely new path between the start and the finish point. The alignment tries to keep as much to the inner curve as possible to reduce the length of the alignment. As can be seen in the results the alignment makes small turns to avoid the environmental and geotechnical zones. The cost for the cut is about 5 million more than for alignment 1, roughly the same as for alignment 2 and approximately 3 million lower than for alignment 3. There is a need of importing material since the alignment does not fulfil the mass balance. The length is 6861 meters which is shorter than for alignment 3 and approximately the same as for alignment 1 and 2. The need of retaining walls is lower than for the alignments 1, 2 and 3 leading to a significant lowering of the total construction cost. This probably depends on that the corridor is less narrow than corridors 1, 2 and 3 enabling the road structure to fit within the corridor without the usage of retaining walls. Since the alignment passes thru several of the avoiding zones the related costs are about one million higher than for the other alternatives.

The alignment Q1 for the corridor generated by Trimble Quantm, makes it possible to see that the avoid zones has a significant effect on the design of the alignment. After the alignment has passed the lake Aspen it turns to the right, following the left border of the natural avoid zone. Then the alignment turns to the left and touches the avoid zone for the town Äs before it continues towards the finish point trying to avoid the cultural-, landscape and geotechnical zones. The length of the alignment is 6872 meters which is almost the same as for alignment 4. The costs connected with the cut are among the lowest of the alternatives, still there is no need of importing material since full mass balance is fulfilled. This indicates that the costs of material transportation and the need of importing material could be lowered by using an alignment optimized by the software. The need of retaining walls along the alignment is lower than for alignments 1, 2 and 3 leading to a lowering of the total construction cost. The reason that the cost of retaining walls is low is probably due to the same explanation as for alignment 4.

5.4 Summary of results for all corridors

The suggested alignments all have a calculate cost of between 109 to 120 million SEK. The most expensive alignment is found in corridor 3. The alignment in the corridor generated by Quantm is the cheapest of the alternatives followed by alternative 4, 1 and 2. Alternative 1, 2 and 3 are likely to have a lower cost than calculated by the software, as the major part of the alignments follows the existing road. The aforementioned will probably lower the cost of preserving environmental values and decrease the need of retaining walls.

The alignment in corridor 4 has the largest impact on cultural zones, still the cost for the alignment is held down as a consequence of the limited need for retaining walls. The alignment in corridor Q1 has the lowest cost related to entering cultural zones; however for alignment 1 and 2 these costs will probably be lower than calculated as the alignments partly follow the existing road. The alignment in corridor 2 is least effected by geotechnical issue zones while the alignment in the corridor generated by Quantm is most effected. In contrast Alignment 2 has the highest costs of disturbing landscape values, while alignment 4 has the lowest. The natural values are most affected by alignment 4 and the least by alignment 2. All together the alignment in corridor 2 has the lowest cost for affecting natural values and possible geotechnical issue zones. Alignment 4 has the lowest cost related to landscape values and alignment Q1 has the lowest cost for affecting cultural values. Alignment 1 affects the total quantity of environmental and geotechnical area zones the least.

The case study shows that the alignment in corridor Q1 is best of the alternative based on the recommendations of the software. However, the cost of alignment 1, 2 and 4 is close to the cost of alignment Q1. As the actual cost of alignment 1 and 2 is likely to be lower than the program predicts, one of these alternatives might be better than alternative Q1.

Studying the alignment in corridor Q1 shows that after the alignment passed the lake it follows within all corridors 1, 2 and Q1 indicating that eider one of these corridors are the best to use for the final design. The pre study made by the Swedish traffic administration assess that by using the current road, the effect on environmental zones is minimized (Trafikverket, 2011 (a)). Based on the pre study and the results from the case study; the most favourable corridor and alignment is probably to follow the existing road to the point where alignment Q1 crosses the road. The designer should create a curve that fulfils both the horizontal and vertical minimum requirements to enable the new alignment to follow alignment Q1 from that point. The same procedure will be made after the alignment has passed the town Äs, to connect the alignment to the path of the existing road as soon as possible. This means that a designer needs to evaluate the results presented by the software, to judge if there may be a better alternative that can be used for the final design.

According to the Swedish transport administration the cost for the reconstructing the entire stretch between Bie and Stora Sundby will be approximately 200 million SEK in 2011 monetary value (Trafikverket, 2011 (a)). The total stretch between Bie and Stora Sundby is approximately 20 kilometres long and the alternative paths outside Äs are about 7 kilometres. The area outside Äs is the only stretch where a partly new road will be built; along the rest of the stretch current road will be reconstructed. The result shows that more than half of the budget will be used when constructing the new road outside Äs, although the stretch is only about a third of the total stretch. However the cost for constructing a new road is probably higher then reconstructing the existing road (Trafikverket, 2011 (a)), indicating that the calculations made by the software are reasonable.

5.5 The usage of Trimble Quantm

The chapter will discuss the usability of the software in the planning process together with a technical evaluation of the software.

5.5.1 Evaluation of the software

The overall impression when conducting the case study is that the software Trimble Quantm is user friendly and easy to learn. The most frequently used tools are logically placed which enable a fast construction of the models. The calculations are relatively fast although they would probably be faster with a better computer. The fast calculations enable many alternative alignments to be analysed in a short time. When working with the design of the alignment, it is important to work with both the horizontal and vertical alignment simultaneously (Robinson & Thagesen, 2004). The software supports this way of working, by automatically chancing the vertical alignment when changes are made in the horizontal and vice versa. This feature helps fulfil the restrictions from the Swedish traffic administration on minimum radius for curvature. One important step in the planning process is the presentation of the alternatives to the Swedish traffic authority (Trafikverket, 2012 (b)). The visualization possibilities in the software are good. The drive through feature shows in 3D the experience when driving on the road, visualizing cuts, fills, bridges and tunnels together with the avoid zones. The visualizations are possible to export enabling for example the drive through visualization to be shown in a power point.

Even though the overall impression of the program is positive, there are some areas of improvement. There is no possibility to change the unit for the parameters in the software. One example is that the cost parameters in the case study were entered in SEK but the software presents the result with a USD prefix.

During the case study there were some technical problems with the software. Without warning the software freezes, this usually happens when changing quickly between the different functions. The embedded system naming the project files, adds "_1" to the name of the file each time the model is changed and saved. For example if the name of the model is Road_1, when changed and saved the new name will be Road_1_1. It is possible to add a note to each of the files, and in text describe what have been changed. The user needs to click on each file in order to see the note. After working with the software a recommendation is to create an own system for naming the files since the embedded system quickly creates many files with similar names.

5.5.2 Usability of the software in the planning process

The result of the case study shows some advantages that could reduce the time of the planning process of road construction. One benefit of using the software is that the time between presenting the alternative corridors and creating the road plan for the new road could be reduced. The software generates an optimal alignment and creates a corridor from that information. As a consequence the work with the road plan, which describes the alignment in detail, is already finished when the program has created the corridor. The software has functions that facilitate the illustration of how the environmental zones affect the final design of the alignment. This feature is useable since the transport administration requires a report that shows all the consultations that have been made and how these have influenced the design of the road (Trafikverket, 2012 (b)).

The aim is to design the alignment to an economic standard that is consistent with the topography to minimize the earthworks (Robinson & Thagesen, 2004). The result of the case study shows the software can support the designer to achieve this. The software compares the cost for a cut or importing material and chooses the most cost efficient alternative.

According to 1 chapter 13§ in the road act (1971:948) the designers of a road construction need to preserve the environmental values as long as preserving them can be made without unreasonable expense. This is supported by the software that considers entering an environmental zone if the cost of entering the zone is lower than the cost of avoiding it. The choice of entering an environmental zone could be argued for by using the calculations of the software. If the designer enters a cost that is considered "unreasonable" on the environmental zone, and the software still chooses this path, it indicates that the cost of avoiding it would be considered unreasonable.

There is no function in the software that takes in to account an existing road. As mentioned earlier, this fact makes the calculations unreliable and having this function would probably change the outcome of the alignment suggested by the software. The pre study assesses that the cost for entering an environmental zone adjacent to the existing road will be limited, as the values probably already are destroyed (Trafikverket, 2011 (a)).

6 Conclusion

The software is user friendly and easy to learn. Some advantages that could reduce the time for the planning process are shown. The calculations are fast which enables the designers to investigate more alternatives in reduced time compared to a traditional planning process. The software supports the designer to work with the horizontal and vertical alignments simultaneously.

A benefit of using the software early in the planning process is that the time between presenting the alternatives for the new road and creating the road plan can be reduced. When the program creates a corridor, the design of the optimal alignment is already finished.

The software has functions that facilitate the illustration of how the environmental zones affect the final design of the alignment. The software has potential to reduce the cost for a project. There are functions that facilitates for the designer to minimize the earthwork and to reduce the impact of zones with environmental value or geotechnical problems.

There are some areas of improvements within the software. The embedded naming system and the reliability regarding the technical function could be improved.

The software Trimble Quantm suggests approximately the same path for the corridor as one made by the designers. Still the software may not present the most suitable alternative directly since there is no function in the software that takes in to account an existing road. As a consequence, a designer needs to evaluate the result given by the software to assess if the result is the best alternative for the final design.

7 Recommendations

Further studies are needed to investigate how the design methodology could be adopted due to the existence of computerized alignment optimizing software.

Suggestions on further work to evaluate the software could be to make a new case study when the alignment for the stretch is decided, to compare that with the optimized alignment generated by Trimble Quantm and calculate the cost difference.

There could also be a study made that evaluate and compare different optimizing software's for alignment optimization to find advantages or disadvantages between them.

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Appendix A

The appendix shows how the alignment in each corridor affected by the avoid zones, environmental value, other avoid zones and geotechnical issues. The alignment in corridor 1, see Figure A28. The alignment in corridor 2, see Figure A29. The alignment in corridor 3, see Figure A30. The alignment in corridor 4, see Figure A31. The alignment in corridor Q1, see Figure A32.

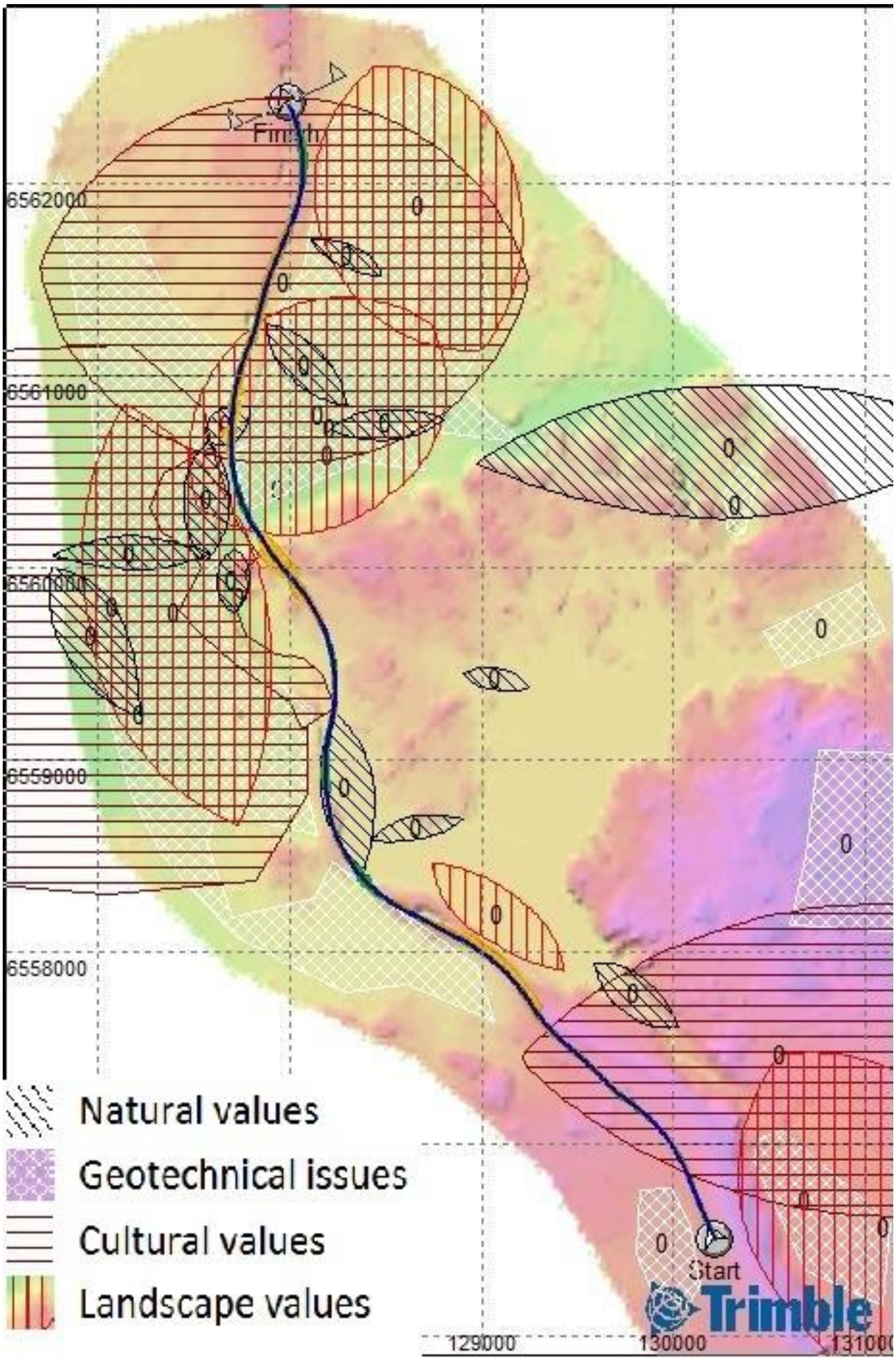

Figure A28 Shows how the alignment in corridor 1 are affected by the avoid zones, environmental value, other avoid zones and geotechnical issues.

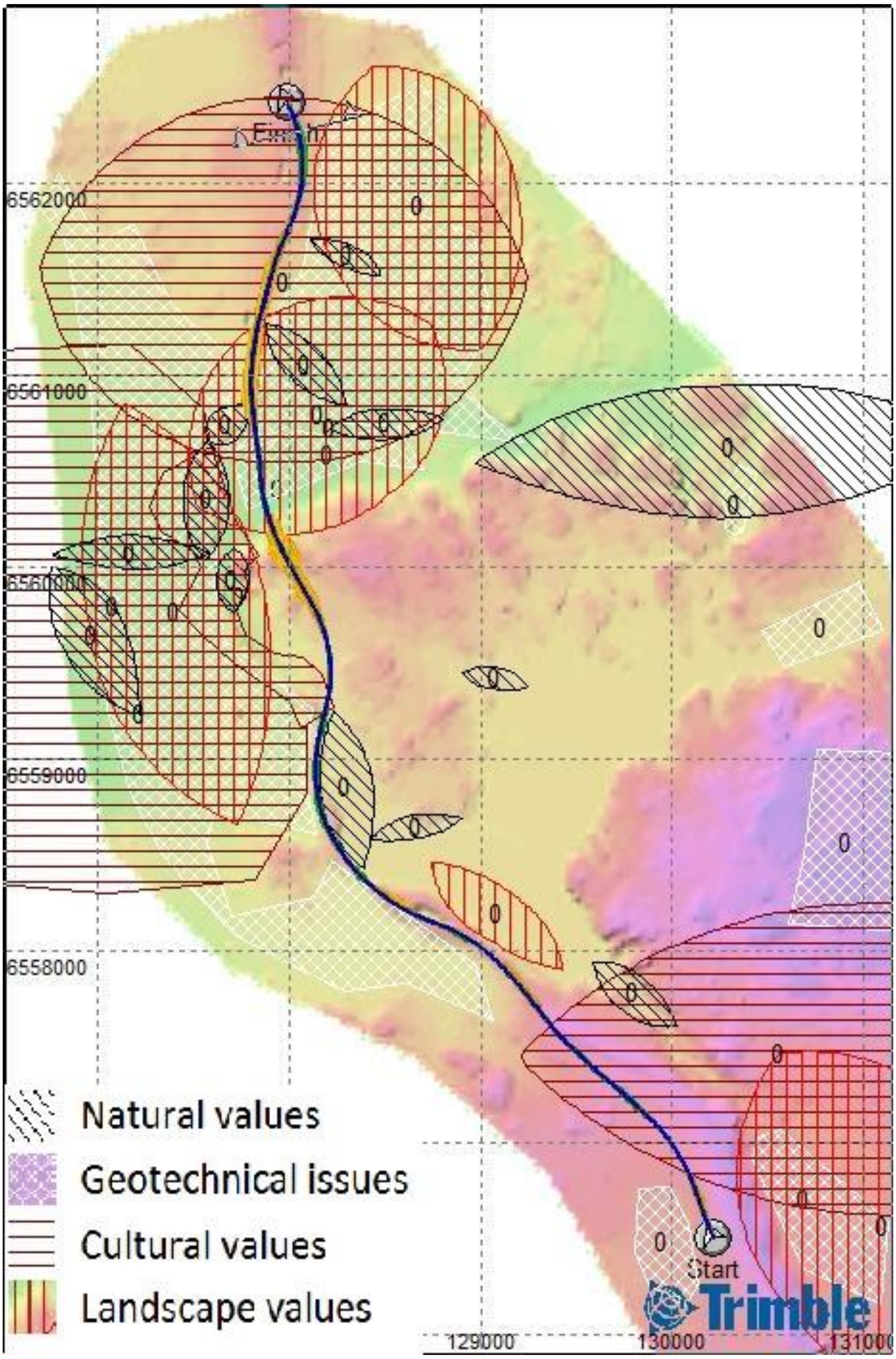

Figure A29 Shows how the alignment in corridor 2 are affected by the avoid zones, environmental value, other avoid zones and geotechnical issues.

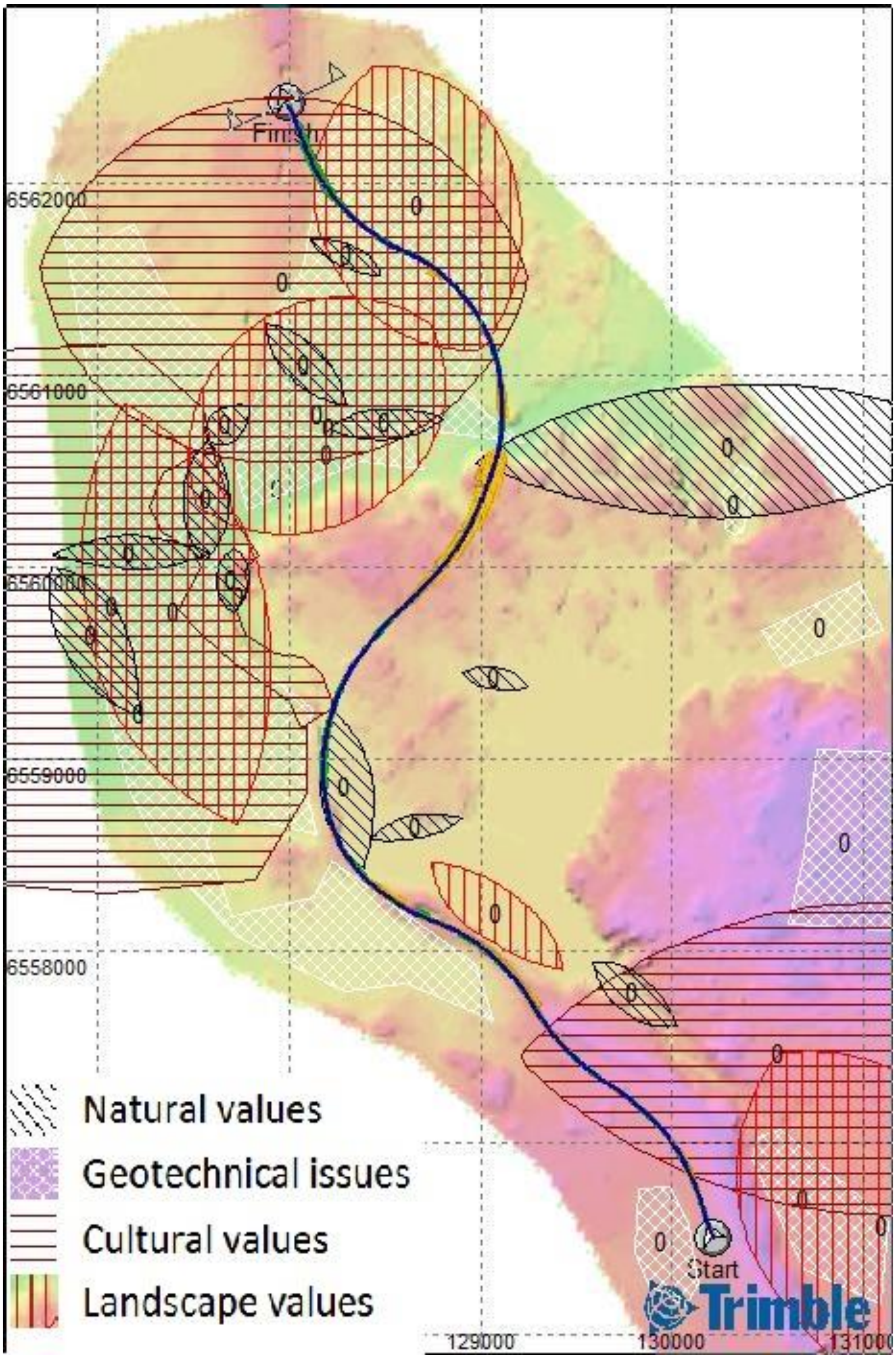

Figure A30 *Shows how the alignment in corridor 3 are affected by the avoid zones, environmental value, other avoid zones and geotechnical issues.*

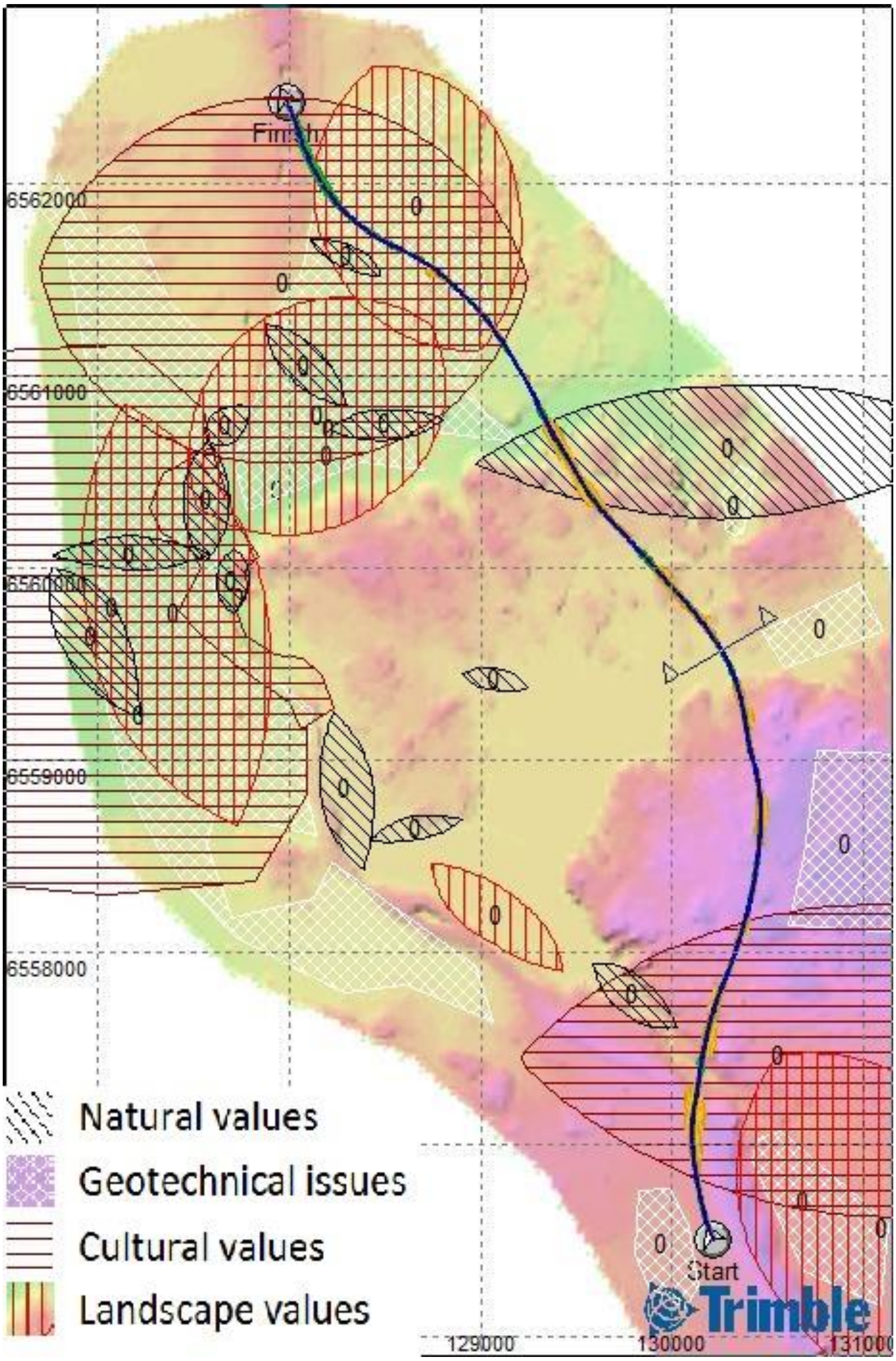

Figure A31 Shows how the alignment in corridor 4 are affected by the avoid zones, environmental value, other avoid zones and geotechnical issues.

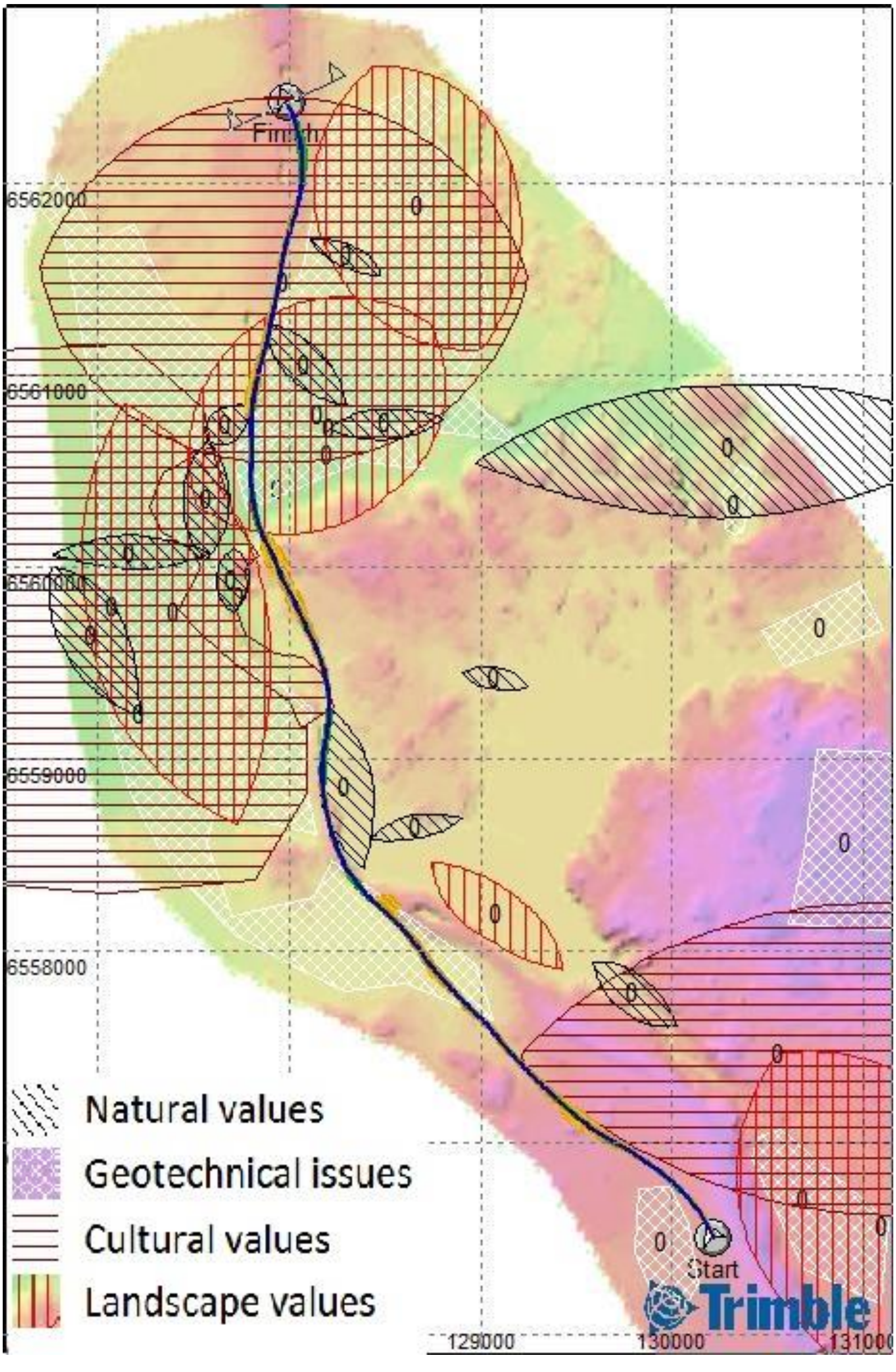

Figure A32 *Shows how the alignment in corridor Q1 are affected by the avoid zones, environmental value, other avoid zones and geotechnical issues.*

Appendix B

The appendix shows the optimized alignment and corridor generated by Trimble Quantm together with the corridors given by WSP (see Figure B1).

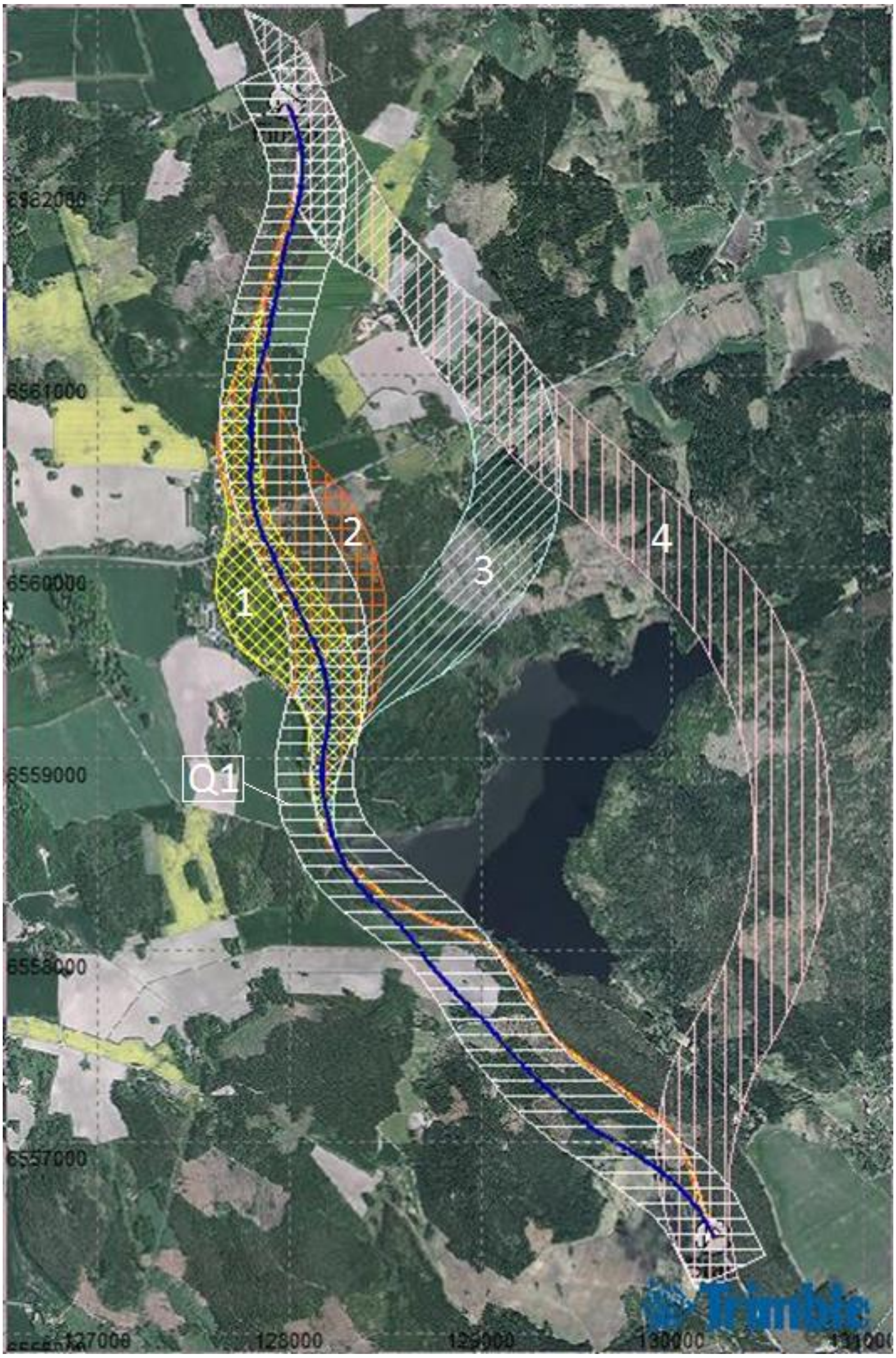

Figure B1 *Shows the optimized alignment and corridor generated by Trimble Quantm and the corridors given by WSP.*