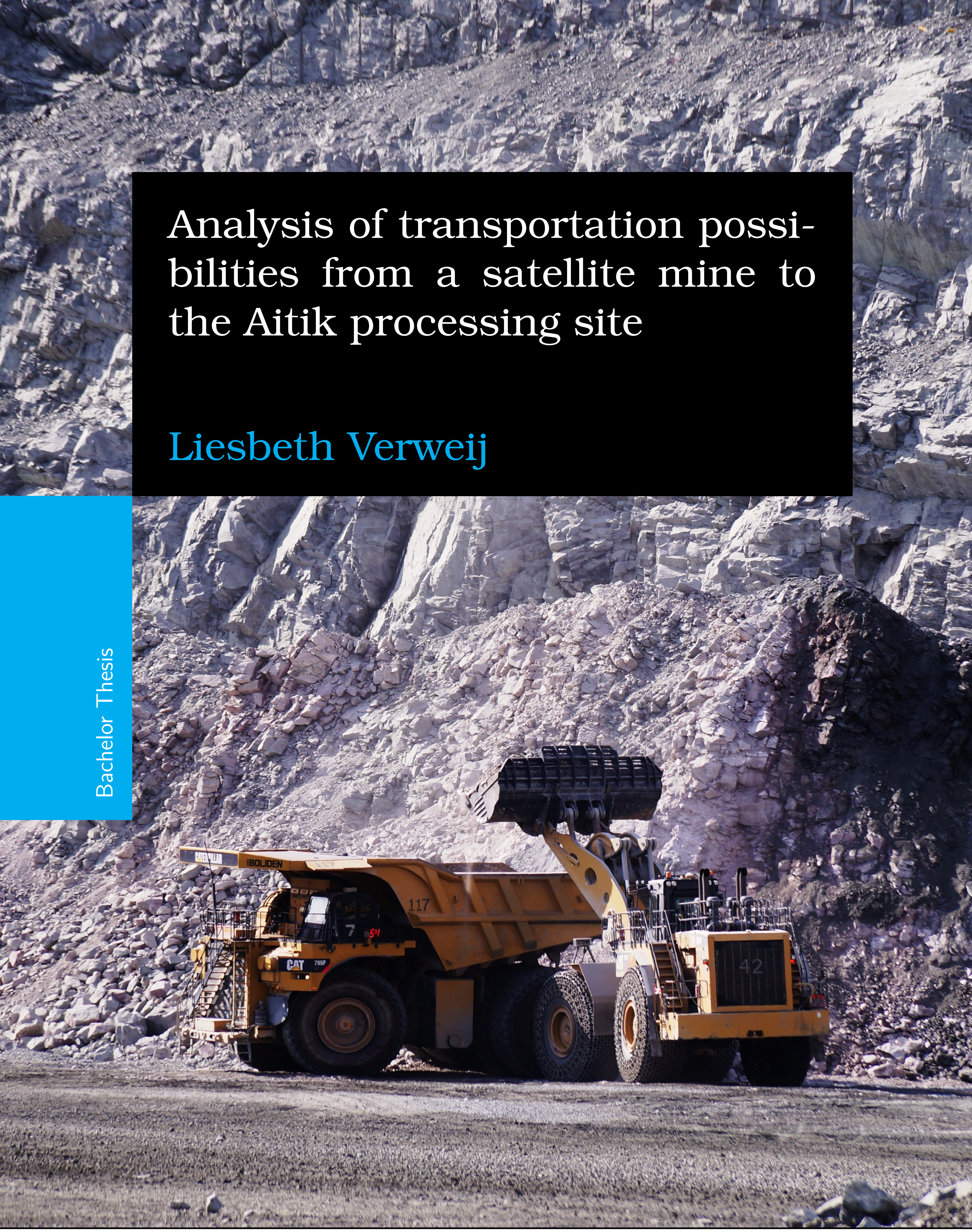
Analysis of transportation possibilities from a satellite mine to the Aitik processing site

Liesbeth Verweij

Bachelor Thesis



TU Delft
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Abstract

The Aitik mine is the largest copper mine in Sweden. In the surrounding area several minor deposits have been found. If these deposits will be mined the ore can be handled in the concentrator of the Aitik mine, which means that the ore has to be transported to the Aitik mine. Transportation options of one of these satellite mines, 15 km away from Aitik, are investigated. This is based on a pre-feasibility study provided by Boliden.

The transportation scenarios of nearby mines have been analysed in order to find similarities to the satellite mine. The similarities are as follows: the Renström mine is located 15 km from the concentrator, the ore of the Aitik mine has the same composition and pit of the Kaunisvaara project is in the same order of magnitude.

Selection criteria are listed, involving limitations, environmental issues and economics. The criteria are listed from low influence to high influence: forest, animals, emission, shareholders, employees, transportation costs, profit, maximum weight and fragmentation size.

Eight different transportation scenarios are listed based on these similarities and selection criteria. Two of these scenarios are further analysed. In these scenarios the ore is loaded on a mine truck to the surface and further transported with highway trucks to the concentrator. One of these scenarios involves stockpiling before the ore is brought to the concentrator, this is found to be the best option.

In this scenario 11 mine trucks with a payload of 50 tonnes, 16 mine trucks with a payload of 25 tonnes, 3 shovels, 1 wheel loader and 4 highway trucks are needed. The total costs of the mining and the transportation to the concentrator will be 36 SEK/tonnes, which is about 5.5 USD/tonnes.

Further investigation can be done by changing the duration of the project, in order to conclude what this will do to the costs. One can also investigate what will happen when the equipment will break down and what will happen when the equipment will be leased from a contractor. Finally, the mining schedule and the amount of equipment need to be geared to each other.

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Glossary

Bench	Describe vertical levels of the hole. Usually on four meter to sixty meter intervals, depending on the size of the machinery that is being used.
CAPEX	Capital expenditures: expenditures creating future benefits.
Concentrator	A milling plant that produces a concentrate of the valuable minerals or metals. Further treatment is required to recover the pure metal.
Conveyor	A rubber reinforced continuous belt supported on rollers called idlers which transports solid materials between stockpiles, surge bins, and feeders.
Crusher	Machine designed to reduce large rocks into smaller rocks, gravel, or rock dust.
Cut-off value	The level of mineral in an ore below which it is not economically feasible to mine it
Cycle time	The period required to complete one cycle of an operation; in this case loading and dumping the ore and waste material
Mine truck	Off-highway, rigid dump trucks pecifically engineered for use in high-production mining and heavy-duty construction environments. (Also haul truck)
OPEX	operational expenditure: ongoing cost for running a product, business, or system.
SEK	Swedish Krona: 1 SEK = 0.1517 USD (CNN Money, 20-05-2014)
Shareholder Value	Shareholder value is a business term which implies that the ultimate measure of a company's success is the extent to which it enriches shareholders.
Skip	A cage used as a lift in (underground) mines.
Stockpile	A large accumulated stock of ore
Till	Unsorted glacial sediment, in this case the type of overburden.

Chapter 1

Introduction

The Aitik Mine is the largest copper mine in Sweden. The mine is situated outside the town of Gällivare in the very north of the country. It is the most efficient open pit copper mine in the world. (Boliden Group, 2014a) In the surrounding area there are several minor deposits, the ore from these deposits might be extracted and transported to the Aitik mine, so that the ore can be processed in the Aitik concentrator. This thesis is about the logistic from one of these satellite mines to the Aitik mine, a distance of about 15 kilometers.

A pre-feasibility study is provided by Boliden. This research is based on this study. The goal is to find the best way to transport the ore from the satellite mine to Aitik. In order to reach this goal different tranportation scenarios can be made involving tranportation in the mine and to the concentrator. This scenarios will be based on the logistics of Renström mine in the Boliden Area, the Aitik mine itself, and the Kaunisvaara project from Northland Resources. The similarities between this mines and the satellite mines are listed. Selection criteria have to be defined in order to determine which scenario is the most appropriate. This scenario will be further analysed.

The objectives in order to determine the best transportation option are as follows:

- How is the transportation done in nearby mines and what are the similarities?
- What are the selection criteria and their influence?
- What are the possible transportation methods?
- What are the costs of the most reasonable scenario?

The current transport methods of the Aitik mine, the Boliden Area and the Kaunisvaara project can be found in chapter two. In the next chapter the selection criteria and their influence are listed. In chapter four the analysis of the different tranportation methods can be found. In respectivelly chapter five and six the conclusion and recommendations are given.

Chapter 2

Current transport methods

2.1 Boliden Area - The Renström mine

The Boliden Area is located in the Skellefte field, which is rich of minerals. The operations consist of a concentrator and leaching plant at Boliden and five mines in the surrounding area. Approximately, 1,700 ktonnes of ore is mined and concentrated in this area every year. The copper and gold concentrates, produced at the concentrator, are sent to the Rönnskär copper smelter. Only one of the mines will be discussed here, the Renström mine, located 15 km away from Boliden, more or less the same distance the satellite mine is located from the concentrator in Aitik. (Boliden Group, 2014b)

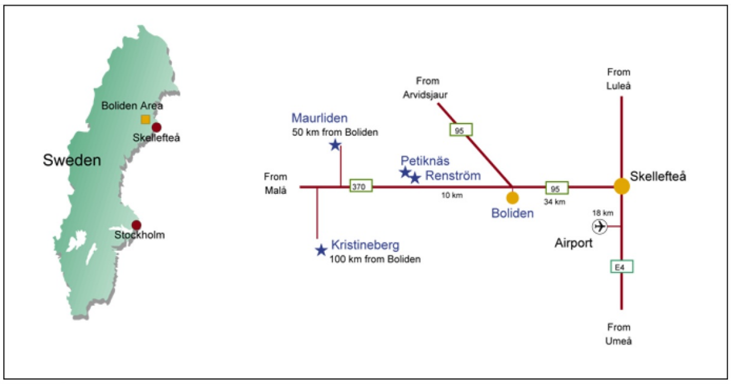

Figure 2.1: The Boliden Area

The Renström mine is an underground mine and it is the deepest mine in Sweden (mining depth 1343 m, may 2013). The ore is very complex: it contains zinc, copper, lead, gold and silver.

The first step to extract the ore is drilling. The face which is drilled is then charged with explosives. The blasting is done three times every day, when the mine workers have their shift change. The ore is loaded in a mine truck by a front end loader and transported to the crusher which is located at 800 meter depth. The crushed ore is transported with a conveyor belt to a skip and is hoisted to the surface by this skip. At the surface the ore is loaded into high way trucks and transported to the concentrator in Boliden. (Fjellström, 2011)

2.2 The Aitik mine

The Aitik mine is the largest copper mine in Sweden and also the most efficient open pit copper mine in the world. It is located outside the town of Gällivare. Approximately 37 Mtonnes of ore is mined and concentrated every year. The mine has a length of 3 kilometer, a width of 1.1 kilometer and a depth of 450 meter (2013). Some of the largest machines in the world can be find in this mine.

The ore has a lower copper grade than the ore of the satellite mine. The amount of ore of the satellite mine will be less, which means that the large scale machines in the Aitik mine; can't be used for the satellite mine. The way of extracting the ore and the transportation method can be compared with that of the satellite mine.

The ore is drilled with the use of an Atlas Copco drilling machine. After that the ore is blasted. This is done once or twice a week, not more otherwise the extraction of the ore will be delayed. The ore is loaded onto mine trucks; they bring the ore to one of the two in-pit crushers. The crushed material is transported to a secondary crusher. From there the ore is transported with a conveyor belt to the storage. Further transportation to the concentrator is also with a conveyor belt. These are the machines used in the Aitik mine (Poggats, 2013):

- 1 Bucyrus 49 Rlll
- 4 Atlas Copco PitViper 351
- 1 P&H 4100
- 2 Komatsu PC5500
- 1 BE 495BII
- 2 Caterpillar 994F
- 23 Caterpillar 793 B& C
- 10 Caterpillar 795 F AC

2.3 The Kaunisvaara Project

The Kaunisvaara Project is a project from Northland Resources. The project consists of two ore bodies, the Tapuli pit and the Sahavaara pit and a processing plant in between; located approximately 100 km north of the Arctic Circle near the village Kaunisvaara. In this region there are low political and legal risks.

The production of the Tapuli mine started in October 2012, there is no production yet in the Sahavaara pit, the company is waiting for an environmental permission before they can start. The ore from the Sahavaara pit contains more sulphur, which makes the handling a lot more complicated. That is the reason the mining started with the Tapuli pit.

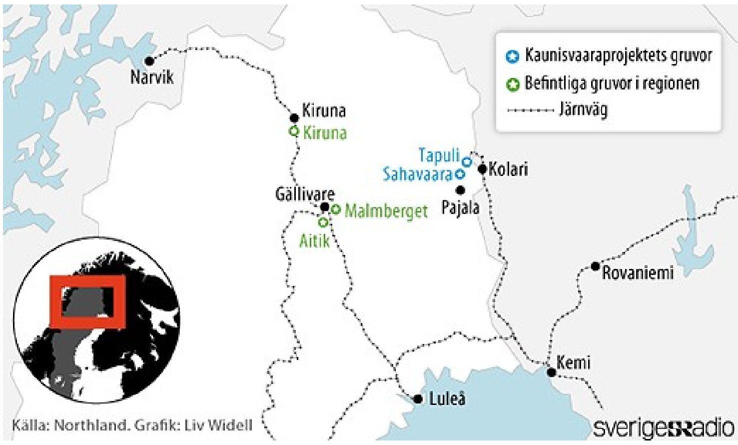

Figure 2.2: Location of the Aitik mine and the Kaunisvaara project

The Tapuli pit will be 2 kilometer long, 200 meter wide and 250 meter deep in the centre. In order to extract the ore from the pit, the ore and waste material are blasted, then loaded onto a truck to the crusher. After the ore is crushed it is dumped by a conveying belt and finally loaded by a wheel loader onto a highway truck. The ore is transported by this highway trucks from Kaunisvaara to Svappavaara.

The maximum loading of the trucks is 90 tonnes, where the normal restrictions are 60 tonnes, the company is trying to get a permission for a maximum weight of 130 tonnes. From Svappavaara the ore is further transported by train to the harbour of Narvik, Norway. This is a large distance for ore transportation, but it is feasible due to the high iron grades. Nowadays 500,000 tonnes of ore is handled each month; this is about 6 million tonnes per year. Once the Sahavaara pit is also extracted the amount of ore will be doubled: 12 million tonnes of ore per year.

Northland Resources is the owner of the machines which are operating in the mine; they have a full service contract, so they don't have any capital and maintenance costs. The highway trucks are leased from a contractor. An overview of all the machines used for the Kaunisvaara project is given below. When the Sahavaara pit is opened, the amount of machines will be expanded. (Northland Resources, 2013)

- 2 Atlas Copco D65 165 mm
- 2 Atlas Copco Pit Viper 271 mm
- 2 hydraulic shovels CAT 6060
- 4 wheel loaders CAT 994 F
- 10 mining trucks CAT 793 F
- 30 highway trucks (leased)

2.4 Overview

Boliden Area - The Renström mine

The Renström mine is an underground operation where the satellite mine will be an open pit. This means that the same equipment as used in the Renström mine can't be used in the satellite mine. The ore is transported from the Renström mine to the concentrator in Boliden, which is a distance of about 15 kilometers, the same distance the ore has to be transported from the satellite mine to the concentrator in Aitik.

The Aitik mine

There is a saying which goes "Everything is bigger in Aitik" and that is really the case. The equipment used in Aitik is far to big to use for the satellite mine. The type of ore is the same, which means that the ore of the satellite mine will be handled in the same concentrator as the ore of Aitik, this might implicate that the fragmentation size of the ore should be the same.

The Kaunisvaara Project

The Kaunisvaara Project has the same order of magnitude as the satellite mine. The equipment used in the Kaunisvaara Project will be sufficient to use in the satellite mine. The ore is transported from the mine to a concentrator over a distance of 150 km. This is done by a contractor. A long distance will result in a long cycle time, which means that a lot of highway trucks are needed. This won't be the case for the satellite mine, but the use of highway trucks from a contractor might be investigated.

Chapter 3

Selection Criteria

3.1 Limitations

In order to determine the transport possibilities with the use of trucks one should take the limitions into account. The most important limitation is the maximum loading weight of the trucks, as they make use of the normal roads. The normal maximum weight is 60 tons. Boliden is allowed to transport 74 tonnes in the Boliden Area. Northland Resources is allowed to transport even 90 tonnes, and is planning to get permission to load even 130 tonnes. There might be a possibility that Boliden is also allowed to use trucks weighing more than 60 tonnes between Aitik and the satellite mine, if that is needed.

Another limitation it the fragmentation of the ore. The hauling trucks will be easily damaged if the ore has a diameter over 200-300 mm. Because of this at least 80% of the ore should have a diameter smaller than 300 mm. If the fragmentation size of the ore exceeds this size after the blasting, the ore has to be crushed.

Limitation can't be neglected, that why they are the most important selection criteria and have the highest ranking as shown in table 3.1

3.2 Environmental Issues

The major part of the population in Sweden lives in the south. In the northern part of the country are many forests and unspoiled nature. The few trees which have to be cut in order to make a road are nothing compared with all the other trees in the northern part of Sweden. That's why the trees are listed low in the ranking.

In these forest live a lot of animals. The amount of the summer population of moose alone is estimated to be 300-400 thousands and there are even more reindeers.(Svenska Jägareförbundet, 2012) When looking for transportation methods one should consider this habitat. It might be good to check for threatened species: in the past a beaver was discovered near the Aitik mine (beavers are protected animals in Sweden). If there are no threatened species in the region of interest, the animals won't be a problem for this relatively small project.

Although the emission from a highway truck is far from the emission of the processing plant, the emission has to be minimized. On Boliden's website the following can be read: "Boliden's aim is to do everything it can to avoid having an uncontrolled effect on the environment, and we are consequently working on formulating a zero philosophy regarding environmental accidents, that includes the tiniest spill." (Boliden Group, 2014c). Emission might have permanent consequences, this criterium will have the highest ranking of the environmental issues.

3.3 Economics

The cost are involved in the determination of the best scenario, the lower the cost the better the scenario, if not conflicting with the other selection criteria. The CAPEX and OPEX are listed in section 4.5.

A profitable project will end in a good shareholder value. This shareholder value is important but not that important as the costs of the employees and de transportation. Because it is important to insure that the project will be profitable at all. The costs of the employees and transportation can be minimized by the duration of the project.

3.4 Overview and ranking

In table 3.1 the selection criteria are conveniently arranged. This is based on the importance of the different criteria. The limitation have the highest rank, there is no possibility to get around these criteria.

Table 3.1: Overview of selection criteria based on ranking

Ranking	**Criteria**	**Class**
low	Forest	Environmental
↕	Animals	Envirionmental
	Emission	Environmental
	Shareholders	Economical
	Employees	Economical
	Transportation costs	Economical
	Profit	Economical
	Maximum weight	Limitation
high	fragmentation size	Limitation

Chapter 4

Analysis of transportation methods

4.1 Scenarios for the satellite mine

There are a lot of options which can be included in the transportation scenarios. Wheel loaders will be needed in the open pit mine for the ore and waste material. The waste will be dumped at the edge of the open pit, so the open pit can be easily filled up after finishing the project. Wheel loaders, mine truck or a conveyor belt can be used for the transportation of the ore in the pit. The ore can be brought to a crusher or to a place where it is stockpiled. After that the ore has to be transported all the way to Aitik, there are several ways how this can be done.

An overview of the different transport possibilities is given in figure 4.1. Every scenario starts with drilling and blasting of the material.

Scenario 1

In the first scenario the ore is loaded on a mine truck with a wheel loader and another wheel loader is loading the ore onto the highway truck, which brings the ore to the concentrator.

Scenario 2

This scenario involves a crusher: a wheel loader will load the material on a mine truck which bring the ore to the crusher. After the crusher the ore will be transported with a conveyor belt to the concentrator. When the fragmentation isn't small enough the ore should be pre-crushed on site. A crusher costs a lot of money and isn't lucrative in a small project like this. Therefore the ore will be blasted in such way that the limitation of fragmentation is fulfilled. This scenario will not be further analysed.

Scenario 3

This scenario only differs from scenario three that after the ore is crushed on site, it will be brought to the concentrator with highway trucks. This scenario will not be further analysed for the same reason as scenario 2.

Scenario 4

In scenario 4 the ore is loaded onto a mine truck which brings the ore to a stockpile. After that the material is brought to the concentrator with highway trucks. Stockpiling may alter the amount of highway trucks, which might result into a cost-effective option. If less highway trucks are needed, the CAPEX will be reduced.

Scenario 5

By loading the ore directly into a highway truck means that the wheel loader has to bring the ore all the way through the pit. Wheel loaders are not designed for travelling long distances. The capacity of a wheel loader is also not large. Even though there are no mine trucks needed in this scenario, this is not a good scenario and so it will not be further analysed.

Scenario 6

It might not be reasonable to use mine trucks to bring the ore al the way to Aitik. However it is found in a previous study about the transport possibilities for the Renström mine, that the use of mine trucks instead of highway trucks would have been more effective. (Fjellström, 2011).

Scenario 7

Another option is to bring the ore with a conveyor belt all the way to the concentrator. In general it can be said that a conveyor belt is only lucrative if there is a lot of ore which have to be transported. The advantages of a conveyor belt are that it is a continuous transportation process and there is less need for work force. It is a disadvantage that the capacity can't easily be changed during the operation, while with the use of trucks; one could vary the amount of trucks of time. When using a conveyor belt in Northern Sweden it should be covered with a shelter so that the ore is protected against the snow. The use of conveyor belts in open pit mines are limited by the fact that the open pit mining goes usually quit deep. (TA1009-4, 2007)

There are a lot of variables which determine the price of a conveyor belt: the type of rubber, the length, width, location (e.g. in-pit, underground), shelter, topography etcetera. This makes it hard to give a good estimation of the price. However, it is certain that this won't be a lucrative option and therefore it will not be further analysed.

Scenario 8

This scenario involves the transportation of the waste. The waste will be loaded onto a mine truck which brings the waste next to the pit. There the ore will be stockpiled until the whole project will be finished.

Only scenario 1 and 4 will be further analysed. This is based on the production schedule of the mine. In the next section the production schedule is given.

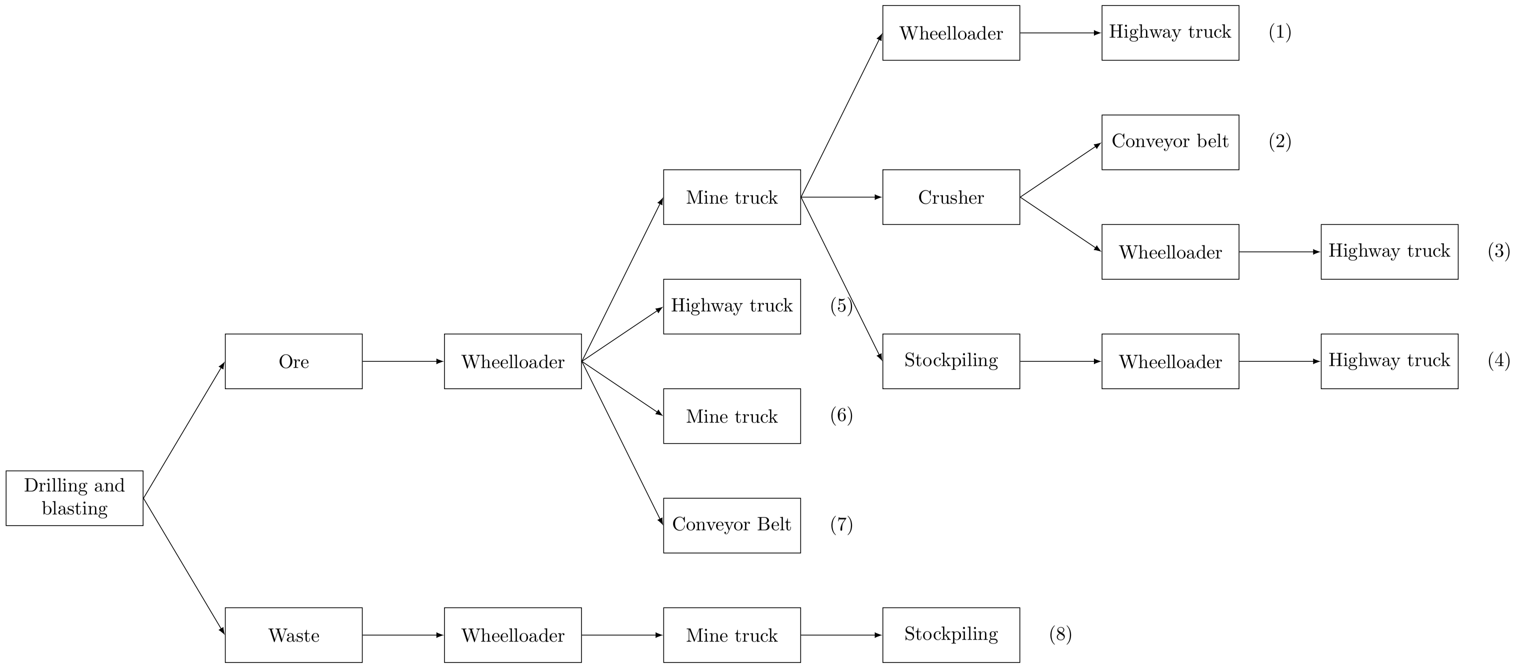

Figure 4.1: Different transport scenarios from satellite mine to Aitik processor

4.2 Production schedule

The production schedule is based on a pre-feasibility study from Boliden. In this study a mine design and block model has been made. From the combination of this mine design, the block model and a solid ore body; the amount of ore, wast and till has been estimated. In table 4.1 the expected amount of ore and waste material for the first five years is given.

In the table the amount of high grade ore, low grade ore and marginal ore can be found. This distinction isn't made in the calculation of the amount of trucks. A cut-off value of 55 SEK is used to determine what material should be considered as ore and what should be considered as waste. In the calculation of the amount of trucks, all the material that meets this cut-off value is considered as ore.

Table 4.1: Production schedule (values given in kton)

	Year 0	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
HG ore	0	155	337	430	502	378
LG ore	0	126	25	75	109	6
Marginal ore	0	369	788	845	739	350
Total amount of ore	0	650	1,150	1,350	1,350	733
Overburden	2,509	682	0	0	0	0
Gangue	1,050	2,485	2,151	2,356	1,173	332
Total amount of waste	3,559	3,166	2,151	2,356	1,173	332
Total	3,559	3,816	3,301	3,706	2,523	1,066

There will be about 250 working days, with 2 shifts, so 16 working hours. The effective working hours will be 75% of the total hours that will be 12 working hours each day. Total amount of working hours each year will be 3000. The average amount of ore and waste which have to be extracted each day is given in table 4.2

Table 4.2: Average production per year(values given in kton)

	Year 0	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Working days	250	250	250	250	250	250
Ore per day	0	2.60	4.60	5.40	5.40	2.93
Waste per day	14.24	12.67	8.61	9.43	4.69	1.33
Total per day	14.24	15.27	13.21	14.83	10.09	4.26
Waste/Ore Ratio	-	4.87	1.87	1.75	0.87	0.45

Table 4.1 and 4.2 show the average amount of ore and waste per day calculated by the amount of ore and waste for each year divided by the amount of working days. It won't be accurate to do the calculation with these values, that is why they will be done using the amount of ore and waste for each bench. This is done in section 4.3

4.3 In-pit transportation

4.3.1 Mining Trucks

Cycle time

If the distance is known the cycle, the cycle time can be calculated using with the average speed of a truck. The combination of the cycle time and the amount of ore and waste will lead to the amount of truck hours for each bench, from this the amount of trucks can be calculated.

The distance is varying during the operation. For every bench and sub-bench the distance is determined using MicroStation. In figure 4.2 the distances for each sub-bench of bench 400 are shown. The method is used for every bench. Besides the distances for the sub-benches there is an additional distance for each bench, the deeper the operation the further the trucks have to drive. With the same program it is found that the additional distance of each bench is 120 meters.

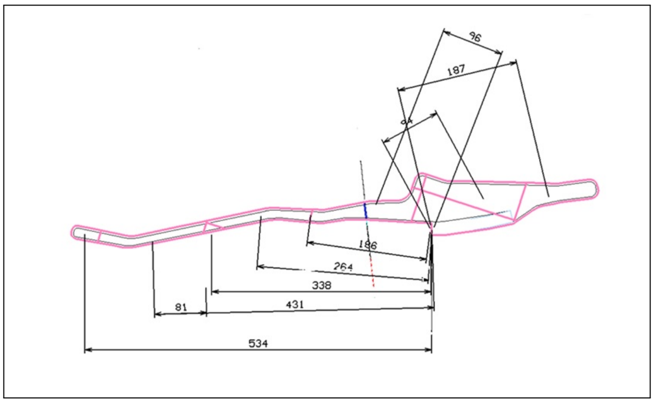

Figure 4.2: Distances for each sub-bench of the deepest bench (400 m)

Now the distance is known for each sub-bench, the cycle time for every bench is calculated. This is done with the use of the parameters shown in table 4.3. The ore and the waste will be brought to a different place, which means that the cycle time for the waste will differ from the cycle time for the ore. The assumption is made that the till will be dumped on the same site as the waste, which means that the cycle time for the till and waste will be the same. With the cycle time the amount of tonnes per hours which can be transported and the amount of trucks needed can be calculated.

Table 4.3: Variables used for calculation of cycle time of mine trucks

Variable	Value
Addition per bench	120 m
Distance waste dump - entrance	550 m
Distance ore dump - entrance	500 m
Average velocity	12.5 km/h
Duration of loading	3 min
Duration of dumping	2 min
Manouvre time	2 min
Delays	2 min

Amount of trucks

The calculation of the amount of trucks is based on the cycle time and task rate. Multiplication of the cycle time with the payload of a truck will lead to the amount of material that can be transported by one truck in one hour (TpH= tonnes per hour). The payload used in this calculation is 50 tonnes (the payload of a Atlas Copco MT5020 or CAT 773B (Caterpillar Inc., 1996)). The number of trucks is found by dividing the task rate with the TpH. The task rate which is used is 1000 tonnes per hour. The time it takes to mine is based on the same task rate.

In another study it is found how long it will take to mine each sub-bench. Based on these data the amount of trucks which are needed on a particular day can be calculated. Some sub-benches are mined at the same time, which means that the equipment should be added. When the mining of a certain sub-bench is finished the equipment can be used for the next sub-bench. In the calculation of the needed trucks the start date and end date of each sub-bench is taken into account.

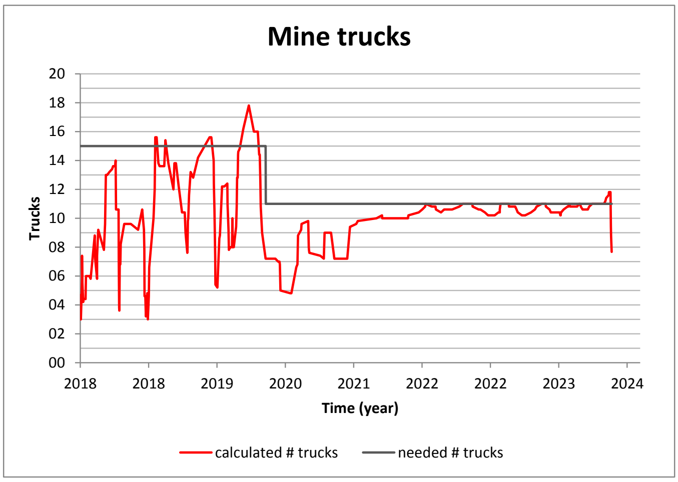

Figure 4.3: Number of trucks needed to transport ore and waste

In figure 4.3 the amount of trucks needed to transport the ore and waste is shown. On yearly scale the amount of trucks can be reduced, by adapting the mining schedule. Figure 4.4 shows the amount of trucks needed for the transportation of the till. These trucks are only needed in the first years of the project, the amount of trucks for till is larger than for ore and waste, despite the fact that there will be less till transported compared to waste and ore material. This is due to the fact that the trucks for the transportation of the till have a payload of 25 tonnes (the payload of a Volvo A25 (Ritchie Bros, 2014)).

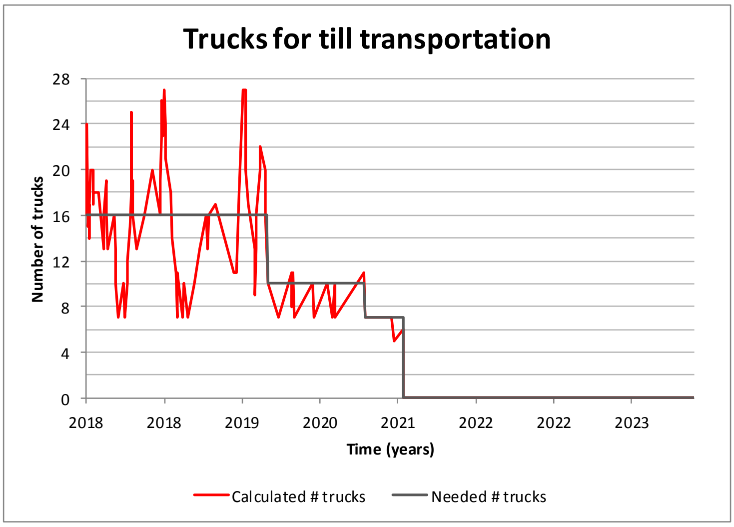

Figure 4.4: Number of trucks needed for till transportation

4.3.2 Shovels

Now that the amount of trucks is known, the amount of shovel which are needed to fill the mine trucks has to be calculated. The amount of shovels is based on how many trucks per hour have to be loaded for each sub-bench. This is based on the amount of cycles per hour.

For instance, if a truck has a cycle time of 20 minutes, it is able to make three cycles in one hour. If there are eight trucks for that bench that means that there will be 3 cycles $\cdot$ 8 trucks = 24 trucks per hour. This means that it should take $\frac{60}{24} = 2.5$ min to load one truck. A reasonable time for truck loading is between 3-5 minutes, so in this case two shovels are needed. This calculation is done for shovels needed for loading a truck with till and for loading trucks with waste and ore.

The assumption is made that one truck will be be loaded with three buckets. Which means that for the waste and ore, one bucket should contain $\frac{50}{3} \approx 17$ tonnes of ore. Assuming that the density is about 1.8 kg/m^3 the capacity of the bucket should be about 9.5 m^3. The payload of a hauling truck transporting till is 25 tonnes. If the density of the till is the same, the capacity of the shovels needs to be about 4.5 m^3. A good scheduling of the usage of the shovels makes it possible to use them for both till, waste and ore; which means that the total amount of shovels will be decreased. This is shown in figure 4.7

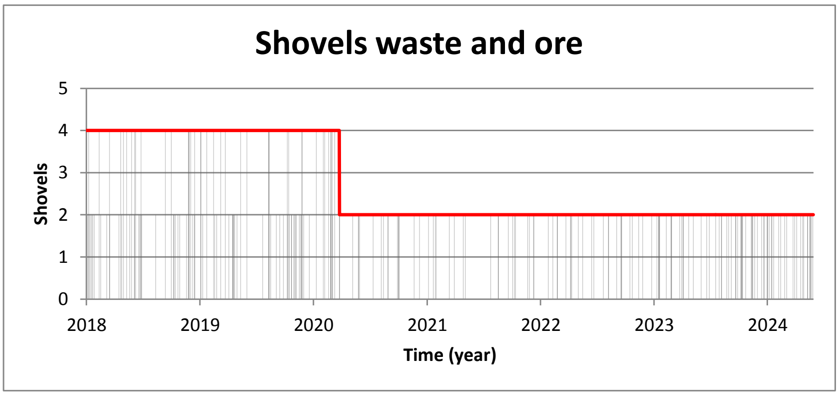

Figure 4.5: Shovels needed for loading waste and ore

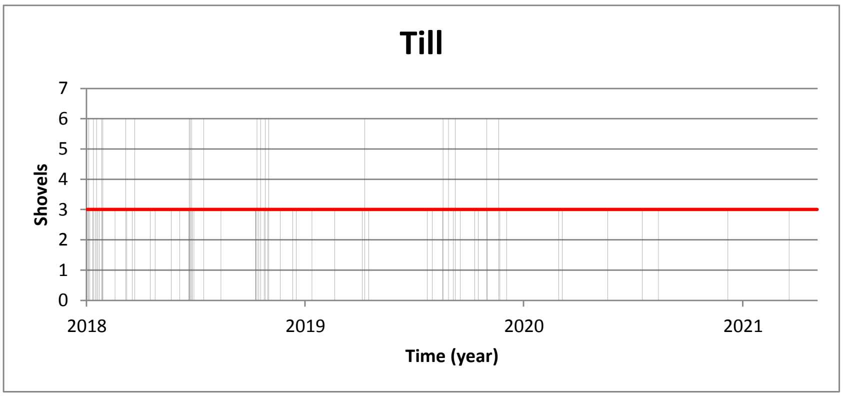

Figure 4.6: Shovels needed for loading till

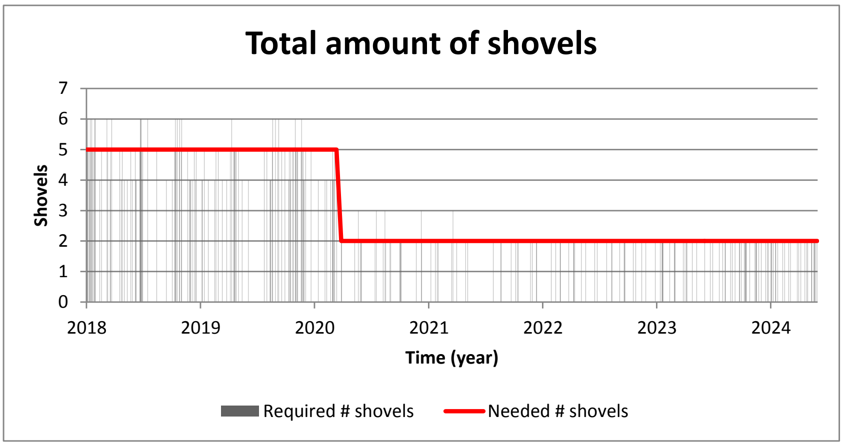

Figure 4.7: Shovels needed for loading

4.4 Transportation from satellite mine to Aitik

4.4.1 Highway trucks

The waste dump is located next to the pit. The ore has to be transported to the concentrator in Aitik, this is done with highway trucks. The amount of highway trucks is based on the amount of ore production per month.

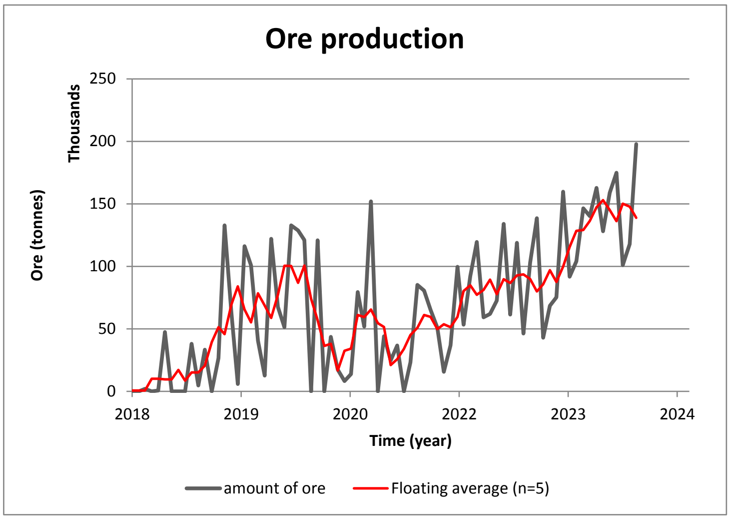

Figure 4.8: Ore production per month

The pattern in figure 4.8 can also be seen in the amount of highway trucks. The amount of highway trucks is based on the cycle time. The cycle time is calculated with the variables given in table 4.4.

Table 4.4: Variables used for calculation of cycle time highway trucks

Variable	Value
Distance	15 km
Average velocity	70 km/h
Duration of loading	5 min
Duration of dumping	3 min
Manouvre time	3 min
Delays	3 min

Unlike the calculation of the cycle time of mining trucks the distance used for the cycle time of highway trucks can be assumed to be constant. This indicates that there will be only one value for the cycle time. The duration of one cycle is found to be about 27 minutes, which is about 2 highway trucks each hour.

It is not very practical to differ the amount of highway trucks with the amount of ore which have to be transported each month. From figure 4.8 it is clear that the production is not really constant, which means that the amount of truck will fluctuate. This won't be the case when the ore will be stockpiled. The fluctuation of the amount of trucks might not be a problem when the highway trucks are leased from a contractor, but even then it might be convenient to stockpile.

There is a maximum amount of ore which can be stockpiled. If the stockpile will be too high the wheel loader will have too much difficulty with loading the ore from the stockpile into a truck. Therefor the maximum height of the stockpile will be about 15 meters. Assuming that the area of stockpiling is 75 by 75 meters, the height is 15 meters and the density of the ore is 1.8 kg/m^3; the maximum amount of ore which can be stockpiled is 150.000 tonnes. If this is just for a small period of time there is no need to cover the ore. In figure 4.9 and 4.10 the amount of trucks with and without stockpiling is shown, respectively for truck hauling 60 and 90 tonnes.

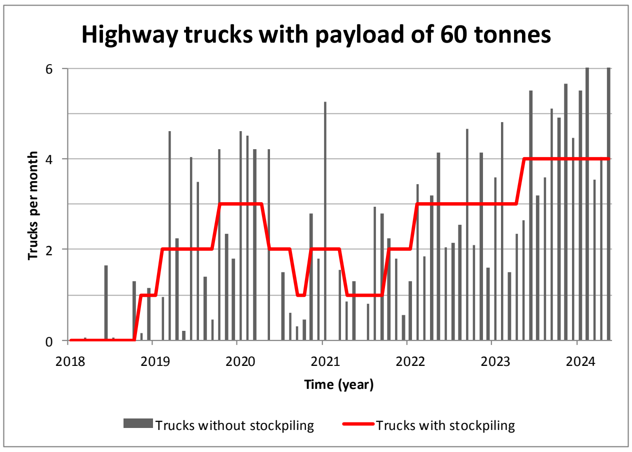

Figure 4.9: Highway trucks (60 tonnes)

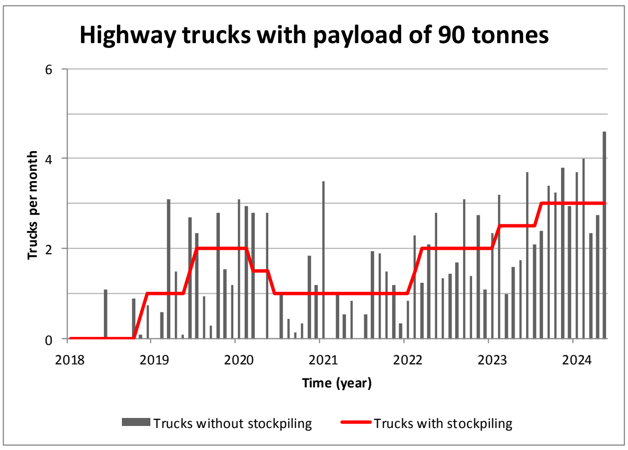

Figure 4.10: Highway trucks (90 tonnes)

4.4.2 Wheel loaders

The ore has to be loaded from the stockpile onto the highway truck, this is done by another wheel loader. One wheel loader will be sufficient to load all the highway trucks. If the highway truck should be loaded in three buckets this means that the capacity of the bucket should be respectively 20 and 30 tonnes for a 60 or 90 tonnes highway truck. This is a capacity of about 11 or 17 m^3.

4.5 CAPEX and OPEX

The costs can be divided into capital expenditures and operational expenditures. The capital expenditures are the trucks and shovels, the amount of trucks and shovels has been calculated. It is common to have spare trucks, in case a truck is broke or needs maintenance. In this operation the concentrator is not depending in the ore from the satellite mine. That is the reason the calculation is done without considering spare equipment. As can be seen in 4.6 less trucks are purchased than calculated. A good scheduling reduces the amount of needed trucks. The operational hours however will stay the same.

The operational expenditures include the working hours which are 16 hours a day, 260 days[1] a year. The engine hours are the effective hours, which are 75% of the day, so 12 hours each day. Maintenance, tire costs and salary are all given in hours. The price of the fuel is given in SEK/liter, therefor the fuel consumption of the trucks is needed per hour. According to (Fjellström, 2011) the consumption of the mine trucks is 36 L/hour and for highway trucks 24 L/hour. For the wheel loaders a fuel consumption is used 24 L/hour, the same as the consumption of the highway trucks.

The values needed to do the calculation of the mining and transportation costs are estimated based on data provided by Boliden Mineral AB.

The total price of the mining and transportation costs are given in SEK/tonnes. The mining costs are divided by the amount of ore, waste and till; the costs of the transportation to the concentrator only by the amount of ore. An overview of the costs is given in table 4.5. Table 4.6 shows all the entries involved in the calculation of the costs.

Table 4.5: Overview of transportation and mining costs

	Mining costs	**Transport costs**	**Total**
Capex (MSEK)	83.9	8.00	91.9
Opex (MSEK)	402.61	47.62	450.23
Total costs (SEK/tonnes)	25.42	10.63	36.04
Total costs (USD/tonnes)	3.86	1.61	5.47

[1] In the calculation 260 days a year is used in stead of the 250 days mentioned in 4.2

Table 4.6: Parameters of cost calculation

Capital costs (MSEK)		
Mine truck (50)	3	33
Dumper (25)	2	32
Highway truck (60)	2	8
Shovel	5.33	16
Wheelloader	2.9	2.9
Total		**91.9**

Operational costs (MSEK)		
Man hours	645996	
Mine truck (50)	293437	
Mine truck (25)	182037	
Shovels	81218	
Wheelloader	26676	
Highway trucks	62628	
Salary (SEK/h)	400	258.40
Fuel (SEK/liter)	4.7	117.28
Engine hours	482887	
Mine truck (50)	219319	
Mine truck (25)	135676	
Shovels	60914	
Wheelloader	20007	
Highway trucks	46971	
Maintainance (SEK/hour)	170	60.35
Tires (SEK/h)	40	14.20
Total		**450.23**

Chapter 5

Conclusions

This thesis describes different transportation methods in order to find the best scenario for transportation of ore from a satellite mine to a concentrator 15 km further down.

In order to define scenarios for the satellite mine the transportation methods of three other mines are listed. The similarities between these mines are given. The distance between the satellite mine and the concentrator is more or less the same distance as the Renstöm mine is from it's concentrator; the ore mined in the Aitik mine is the same ore as will be mined in the satellite mine and the Kaunisvaara project is about the same size as the satellite mine will be.

The scenarios have to be distinguished from each other in order to conclude which is better, this is done using selection criteria. Different aspect have been taken into account: limitations, environmental issues and economics. This results in the following selection criteria sorted from low significance to high significance: forest, animals, emission, shareholders, employees, transportation costs, profit, maximum weight and fragmentation size.

Based on the current scenarios in the three other mines and the selection criteria, eight different transport scenarios are listed. Two of these scenarios are found reasonable for further analysis. In these scenarios the ore is loaded by a wheel loader onto a mine truck, this mine truck will bring the ore to a stockpile in one scenario or the ore will be directly transported to the concentrator in the other scenario. It is found that the project will not be reasonable when there will be no stockpiling.

The costs of the option involving stockpiling is calculated. This price is set up by both the mining costs and the transportation costs and is found to be 36 SEK per tonnes, which is about 5.5 USD per tonne.

Chapter 6

Recommendations

Mining schedule
The mining schedule is based on the assumption that the maximum needed amount of shovels is two. In the calculation of the shovels it turned out that more than two shovels are needed. This means that the mining schedule and the equipment need to be geared to one another.

Duration of the project
It might be good to calculate what the effect is of altering the duration of the project on the price. If the duration will be shorter, more equipment will be needed. More scenarios have to be investigated in order to find the optimal duration of the project.

Contractor
For the calculation of the costs, the assumption is made that Boliden will be the owner of the equipment and highway trucks. A further study has to be done to conclude if this is the best option. In this study there can be distinguished between two scenarios: all the equipment will be leased from a contractor or only the highway trucks will be leased.

Spare equipment
In the calculation the acquisition of spare equipment is discarted, because the concentrator is not depending on the input of ore from the satellite mine. It can be investigated what will happen if one (or more) trucks will be broken down.

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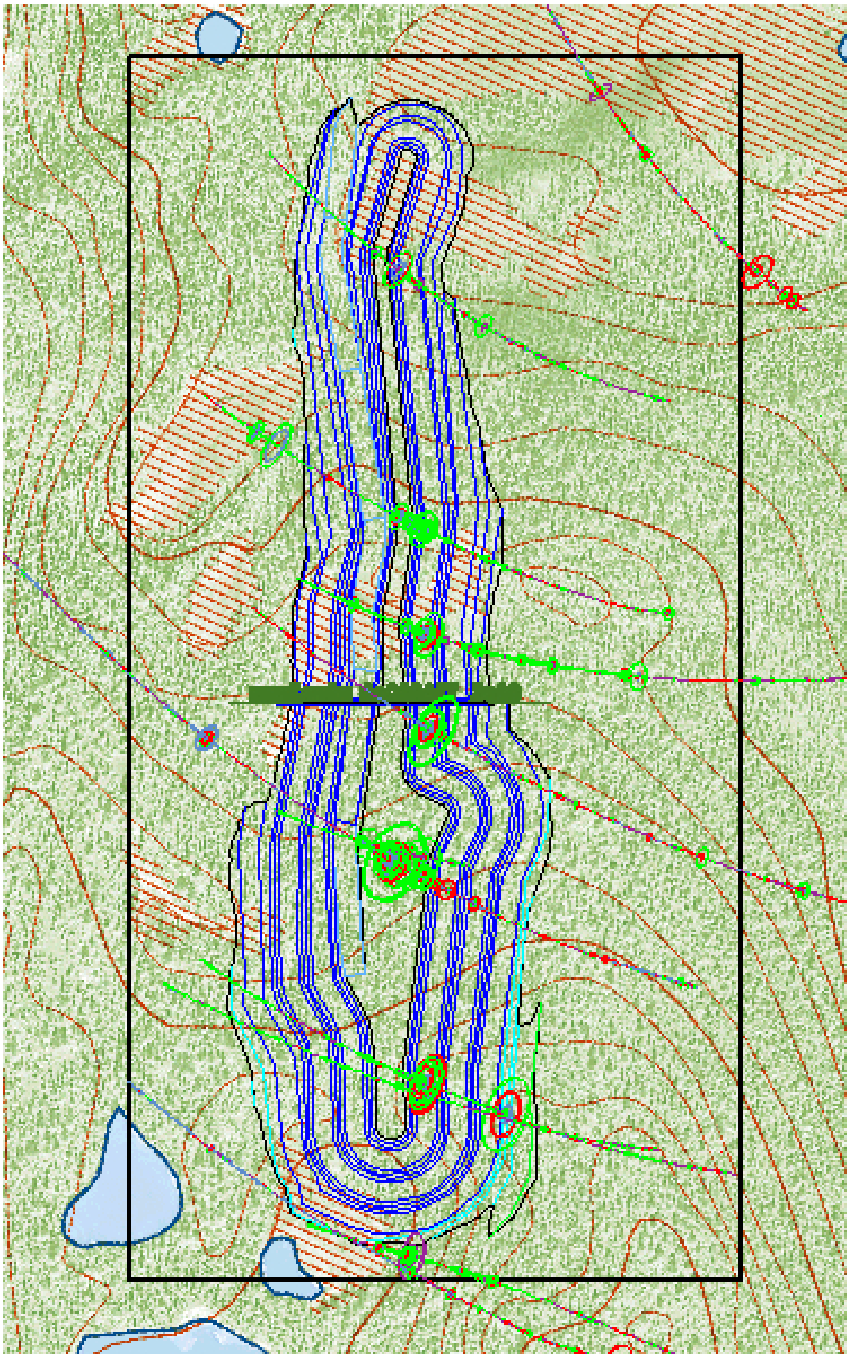
Appendix I



Map of the Nautanen pit (scale 500m x 1000m)

Appendix II

Capacity of Hauling Trucks
(tonnes)

Volvo

A25 C 4x4	22.5
A25C 6x6	22.5
A25D	24
A25E	24
A25F	24
A30	28
A40D	37
A40E	39
A40F	39
A40G	39

Caterpillar

CAT 740	43.8
CAT 769D	36.8
CAT 771D	40
CAT 773D	52.3
CAT 775D	60
CAT 777D	97
CAT 785B	136
CAT 789B	177
CAT 793C	218

Capacity of Wheelloaders
(m^3)

Volvo

L40	1.4
L50E	1.2
L60E	1.8
L60F	1.9
L70F	2.3

Caterpillar

Ore handling

CAT 914G	1.1 - 1.3
CAT 924F	1.4 - 1.7
CAT 928G	1.7
CAT 938G	2.4
CAT 950F	2.5 - 2.9
CAT 950G	2.7
CAT 980G	4.2
CAT 992G	9.5 - 11.5

Waste Handling (tonnes)

CAT 938F WHA	16.325
CAT 950F Series II WHA	20.28
CAT 966F Series II WHA	26.4