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PAJALA MINE ROAD TRANSPORT OPTIONS – SUMMARY REPORT

Summary report 17.1.2012

ABSTRACT

Northland Resources Ltd has scheduled the opening of an iron ore mine in Kaunisvaara in the municipality of Pajala in Northern Sweden in 2013. As there are no railway connections to harbours, the company plans to annually haul five million tonnes of mined ore concentrate by trucks on public roads from Kaunisvaara to Svappavaara railway dock. Northland plans to reach this full production tonnage by 2015. This huge haulage project means in practice that there will be trucks driving at intervals of a few minutes 24 hours per day every day of the year resulting in impacts on roads, bridges and people living in the vicinity of the Kaunisvaara – Svappavaara road.

The current road connection consists of relatively weak roads and bridges that need to be strengthened before the haulage project starts. Northland Resources has expressed an economic interest in using heavier truck options in the haulage project greater than the current permitted maximum 60 tonne trucks. To examine this, The Swedish Transport Administration and Northland commissioned a risk analysis and socio-economic analysis to study the impact of different haulage options on the current road and bridge condition, as well as the improvement need to bring them up to a level suitable for standard 60 tonne trucks.

In addition to the standard analysis, a further analysis was carried out to identify the extra strengthening and other special arrangements needed if heavier trucks (72 tonnes, 90 tonnes, 136 tonnes, 146 tonnes and 153 tonnes) were to be used. An evaluation of noise impact and noise protection measures was also made. Finally a socio-economic analysis was carried out into what would be the most cost effective transportation solution for all the interested parties and for the environment.

The ROADDEX project was asked to participate in the project due to their experience in similar projects in the Northern Periphery area.

The field data for the analysis was collected in winter, spring and summer 2011 using mobile laser scanning techniques, GPR, HWD with time history data, thermal cameras, digital videos and visual inspection, drilling, sampling and laboratory analyses. The knowledge of local maintenance experiences was also utilized in the analysis. Socio-economic and noise analysis were made based on field visits and map evaluations.

The results of the road impact analyses showed that 96 % of the road would have problems within one year of haulage starting. New structures were designed for these areas to give 20 years of service life. On the weakest sections a new third lane was recommended to be built alongside the old weak road. This lane will also act as a passing place for other traffic. In addition, at least two climbing lanes for steep hills were recommended together with a geometry improvement to one identified section are recommended. Road drainage was to be improved to Class 1 before the strengthening measure were carried out. The cost of the overall work was estimated to be 377 mill SEK for haulage by 60 tonne trucks. If heavier truck options are used the extra strengthening costs for the roads were estimated as 12.5 mill SEK. Unexpected costs and the cost of project management are not included in these costs. In addition it was strongly recommended to widen the road as the road shoulders of the current road are weak.

The results of the calculations on the different truck options showed that the major problem in using heavier and longer trucks was the high vertical displacement produced in weak subgrade soil sections during spring thaw periods and in the summer, and long road recovery times. These problems could be reduced however with the construction of 'third lanes'. It was found that all of the heavier truck options fitted with dual tyres were friendlier to the asphalt pavement than a standard 60 tonne truck.

The results of the bridge analyses showed that some bridges needed to be strengthened, especially if the heavier haulage options were used. The cost of this work was estimated to vary between 36 mill SEK and 69 mill SEK depending on what truck options was used.

The Swedish target values for noise levels in housing environments are:

- 30 dBA equivalent level indoors
- 45 dBA maximal level indoors at night (may be exceeded at most five times per night, 22-06 o'clock)
- 55 dBA equivalent level outdoors (at facade)
- 70 dBA maximal level at patio in connection with dwelling (may be exceeded at most five times per hour, in daytime).

It is a requirement that these values are not exceeded on new construction, substantial rehabilitation or reconstruction work. The rehabilitation of the Kaunisvaara-Svappavaara road will most likely be regarded as a "substantial rehabilitation" and the target values enforced accordingly.

The noise analyses identified that there were approximately 170 houses located within the >70 dBA maximum area and the costs of their improvement was estimated at 32 million SEK.

Finally a traffic economic analysis was carried out using information from all of the above. This showed clearly that it was more profitable overall to transport the ore with heavier trucks, compared to transporting it with 60 ton trucks. The socio-economic costs varied from 1,330 million SEK when using standard 60 ton trucks, down to 1,088 million SEK with 153 ton double link option. The net theoretical annual operator gain for the heavier truck options varied from 86 million SEK when using a 72 ton truck, up to 191 million SEK when using a 153 ton truck option. The differences between the costs and benefits for different double link options (136 ton, 146 ton and 153 ton) were not big. Unexpected costs and the cost of project management are not included in any of the above costings.

ACKNOWLEDGEMENTS

This report is a summary report from the different research reports and work reports focused on the analysis of different impacts of road transport options on the Kaunisvaara – Svappavaara. It summarizes the findings of the following reports:

- “*Pajala Road Impact Analysis*” by Timo Saarenketo, Annele Matintupa, Petri Varin, Pauli Kolisoja, Tomi Herronen and Anssi Hiekkalahti, made mainly in Roadscanners Oy.
- “*Vägbroar på sträckan mellan gruvan och Svappavaaram – Utredning av broarnas kapacitet att klara kommande transporter*” by Anders Stenlund, Trafikverket, Luleå
- “*Buller – malmtransporter Kaunisvaara- Svappavaara*” by Gunbritt Mariedahl, Trafikverket Luleå
- “*Optimering av lastbilskonfigurationer för gruvtransporter i Pajala – Trafikekonomiska överbäkanden*” by Jouko Säisä, Vectura

The authors of the report would like to thank all authors and other persons involved in the work for their co-operation.

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1. INTRODUCTION

Northland Resources Ltd has decided to open an iron ore mine in Kaunisvaara in Pajala municipality in Northern Sweden in 2012-2013. Starting in January 2013, the company plans to annually transport five million tonnes of the mined ore concentrate on trucks to a new terminal in Svappavaara from where it will be hauled by train to Narvik harbour in Norway. Five million tonnes per year will be hauled when Northland reaches full production, currently planned for 2015.

The transportation route commences on Road 99 to Pajala, then road 395 to Vittangi and further on to Road 45 to Svappavaara, and finally the E10 to the Svappavaara railway dock intersection. The total length of the public road involved in the ore transportation, owned and managed by the Swedish Transportation Administration, (Trafikverket), is roughly 157 km. These are mainly typical low traffic volume roads in Northern Sweden that have problems with frost action and permanent deformation. Along the route there are 10 bridges. Some of these bridges are old with relatively weak structures.

Trafikverket therefore needed to have a risk analysis of the available lifetimes of the existing roads and bridges if and when the heavy haulage began. The risk assessment method chosen was the risk analysis technique which had proven to work well in the EU ROADDEX project. In addition, new and emerging road survey technologies, such as laser scanning, were utilized for the first time in the project.

Due to the enormous amount of ore concentrate to be hauled to Svappavaara, Northland is naturally interested in optimizing the transportation costs. In practice, this means assessing the possible exemptions available to allow for the use of heavier and longer trucks than the standard maximum 60 tonne trucks. The Swedish Transport Administration, on the other hand, is very aware that the roads and some of the bridges on the route are too weak even for haulage with standard 60 tonne trucks, such that the road needs strengthening anyway, even before haulage starts. It was therefore also practical to analyze and evaluate the impact of heavier vehicles on the road.

In order to carry out the analysis, a range of different total weight options for the trucks was proposed: 72 tonnes, 90 tonnes, 126 tonnes and 170 tonnes with axle weights varying from 8 tonnes to 12 tonnes. The length of the longest option was 37 m. After preliminary evaluations, the trucks options were changed to be 60 tonnes, 72 tonnes, 90 tonnes, 136 tonnes, 145.5 tonnes and 153 tonnes.

This report summarizes the survey and research done during the project in 2011. The report provides information about road structures in three dimensions (3D), and their current structural and functional condition. It also presents the results from the remaining lifetime calculations for the road after the haulage starts. In addition the report presents new design structures and cost estimates for the road strengthening that should be completed before transportation starts. Finally, the report presents socio-economic impact analysis results for the different heavy haulage options together with information on the socio-economic transportation options. These will be based on the contents of this report, a similar report on the bridges along the route, and reports on noise impacts.

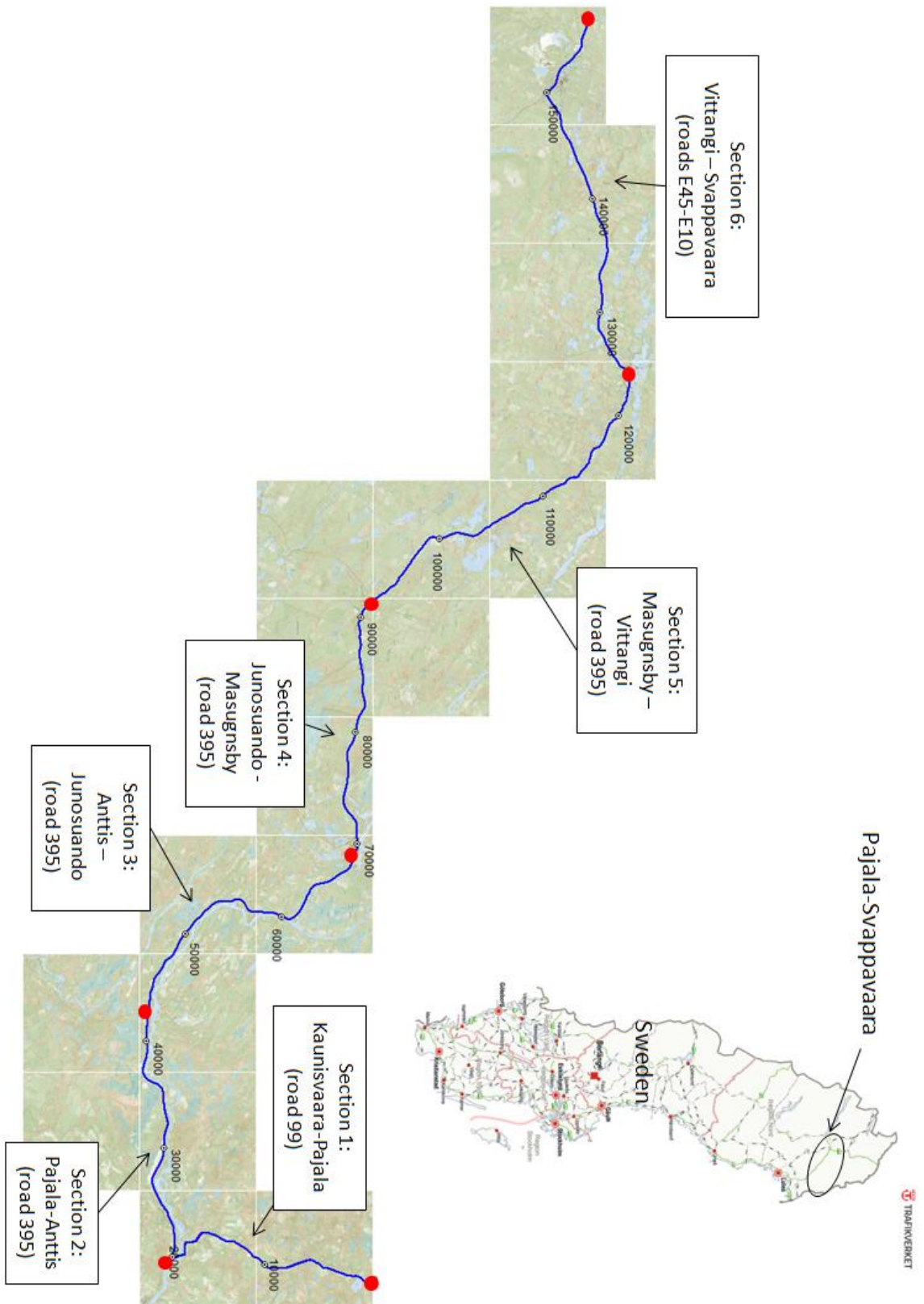


Figure 1. Pajala – Svappavaara road and its subsections.

2. SURVEY AND ANALYSIS TECHNIQUES

2.1. ROAD CONDITION SURVEYS, RISK ANALYSES AND STRENGTHENING DESIGN

The road data in the project was collected using the latest survey technologies in order to provide as good a diagnosis as possible. These surveys included mobile laser scanner mapping for point cloud data, technical road maps and frost heave measurements, ground penetrating radar (GPR) surveys for structural analysis, heavy weight deflectometer surveys (HWD) for bearing capacity analysis, digital video data collection and pavement distress analysis, drainage analysis, sampling and laboratory analysis for material quality evaluation, profilometer data analysis for road performance history, and accelometer and GPR bouncing analysis for road roughness evaluation.

The mobile laser scanning technique using the GeoVap quantum 3D mobile laser scanner technique was used for first time in the world to analyse continuous frost heave along the whole road section (Figure 2.1). In addition the road construction history and maintenance experience was recorded through a site visit and interview with the local maintenance expert.



Figure 2.1. GeoVap Quantum 3D mobile laser scanner vehicle on the Pajala road in April 2011 (left) and an example of point cloud frost heave model made in this project (right).

The collected data was processed and analysed mainly by RoadDoctor Pro software. This software enables the combining of GPR, HWD, IRI, rutting and other data together with videos and maps. The Road Doctor Pro software was used to calculate Swedish Bearing Capacity Indexes and layer moduli of the road in combination with Elmod back calculation software. The ROADDEX Odemark dimensioning analysis, also built-in, was used for initial bearing capacity calculations, and Swedish PMS-objekt software was used in the design of strengthening measures. Bisar® software, based on linear elastic theory, was used for the strengthening design for extra heavy loads and for the evaluation and comparison of the different truck options.

Road Doctor Pro software was also used to classify the road into five classes based on the risk for road failures once the heavy haulage starts. The classes and their criteria were as follows:

- Class 1: Strong road section, no risk major for immediate failures. Pavement fatigue will follow normal road lifetime prediction models.
- Class 2: Relatively strong road. Road damage will appear quickly only in extreme loading conditions or due to poor drainage maintenance etc.

- Class 3: Adequate road section. The risk will mainly appear during a particularly bad spring thaw weakening period.
- Class 4: Weak road section. High risk for road failures especially during the spring thaw weakening period. Strengthening strongly recommended.
- Class 5: Extremely weak road section. Severe damages can be predicted immediately after heavy haulage starts – should be strengthened immediately

2.2. BRIDGES

Bridge analyses were based on the bridge database information held by Trafikverket. Bearing capacity investigations included the calculation of the strength and fatigue of bridges for a range of heavy vehicles with variable length, axle distance, total weight, axle loads and load passages.

2.3. NOISE ANALYSIS

The goal of the noise analysis was to identify the noise impact of the iron ore truck transportation on people living close by the transportation route. A further goal was to estimate the types and costs of noise reduction measures needed to reduce the noise to the allowed levels.

It was not possible however to come to a final judgment on noise impact during the course of the analyses as the type of the truck had not yet been defined and as a result its noise properties were not known. What can be said is that the extent of the noise problem will be equally great regardless of the type of vehicle to be used. The noise disturbance characteristic will be different if there are fewer heavy vehicles compared to more frequent 60 tonne truck passes. The complexity of the issues surrounding noise is judged not to be decisive for the choice of vehicle.

The Swedish maximum values for noise levels in housing environments that are not be exceeded at new construction, or substantial rehabilitation, or reconstruction of a road are:

- 30 dBA equivalent level indoors
- 45 dBA maximal level indoors at night (may be exceeded at maximum five times per night, 22-06 o'clock)
- 55 dBA equivalent level outdoors (at facade)
- 70 dBA maximal level at patio in connection with dwelling (may be exceeded at maximum five times per hour, in daytime).

The action values for the measures, i.e. the noise levels where noise reduction measures have to be implemented are:

- 65 dBA equivalent level, outdoors (at facade)
- 55 dBA maximal level indoors at night (may be exceeded at maximum five times per night, 22-06 o'clock) (this roughly the same value as 80 dBA maximal level outdoors)

The rehabilitation of the Kuunisvaara-Svappavaara road will most likely be regarded as a "substantial rehabilitation" in which case the maximum noise values above be enforced.

As the type of trucks and their noise properties were not known at the time of the analysis the noise impact calculations were made using the Nordic Calculation Model, without adjustment for vehicle type, and only the "maximum noise levels" were calculated. The actual requirements for the noise properties of the trucks to be used can be defined later when the final selection of truck has been made.

Houses suffering from noise impact were defined using a GIS based calculation model (Metria) and Google Earth maps. Following this an estimate of the appropriate noise reduction measures

was made and the costs calculated. Two types of houses were located and classified: 1) houses with noise levels >70 dBA maximum and 2) houses with noise levels >80 dBA maximum.

2.4. COST BENEFIT AND SOCIO-ECONOMIC ANALYSIS

The goal for the cost benefit and socio-economic analysis was to calculate the traffic operating effects and carry out an aggregated assessment, including road improvement costs, to identify the optimal vehicle configuration. This meant making comparative calculations of the different transport options, rather than a more complex, comprehensive socio-economic calculation of mining transports.

The economic effects of the heavy traffic were calculated using EVA 2.58 software. This program calculates the effects of traffic and evaluates them in monetary terms. It is well suited to manage analyses of separate rehabilitation measures on the road network, but it can also be used for analyses of special cases, as was the case for this commission. The program was mainly used for calculating the traffic operating effects of the different truck combinations.

The models included in EVA are:

- Travel time model calculating travel time consumption
- Vehicle consumption model, calculating
 - Vehicle costs
 - Fuel consumption
 - Exhaust emissions (NOX; VOC; CO₂, SO₂ and particles)
- Traffic safety model, projecting
 - Number of accidents
 - Number of fatalities and injuries
 - Number of animal accidents
- The routine- and planned maintenance model, calculates
 - Costs for normal routine- and planned maintenance measures
 - Travel time additions due to slippery roads

EVA utilizes data from the National Road Data Bank (NVDB) but also requires input from field studies such as descriptions of crossings, visibility class, properties of adjacent areas, separation between vehicles and unprotected road users etc.

The average daily traffic (ADT) is an important input in EVA and was calculated for the different truck configurations. The prerequisites were that 5 million tonnes of mining product were to be transported annually from Kaunisvaara to Svappavaara. Each respective truck configuration carries different loads which result in differing ADT figures (traffic in both directions) as shown in Table 2.1. These ADT figures were added to the existing traffic flows on the Kaunisvaara-Svappavaara road sections.

Table 2.1. ADT resulting from different truck configurations, assuming 5 million tonnes haulage per year

| | Konfigurationer | | | | | |
|-----------------|-----------------|----------|----------|-----------|-----------|-----------|
| | Konf. 60 | Konf. 72 | Konf. 90 | Konf. 136 | Konf. 146 | Konf. 153 |
| Lastvikt | 37 | 48 | 63 | 109 | 119 | 126 |
| ÅDT * | 740 | 571 | 435 | 251 | 230 | 217 |

* givet utskęppning 5 miljoner ton och transporter årets alla dagar (inklusive helger)

The input parameters for the calculations are described in detail in the work report “*Optimization of truck configurations for mining transports in Pajala*” by Jouko Säisä.

3. THE EXISTING ROAD AND CONDITION

3.1. STRUCTURAL AND FUNCTIONAL CONDITION OF THE ROAD

The structural history of the Kaunisvaara to Svappavaara road varies along its length. Parts of the road comprise old gravel road sections that have been widened and strengthened, and parts of the road have been constructed in the 1970's and later. Road strengthening and repair of local frost heave damages has also been carried out on some sections. Analyses of condition trends show that both rutting and roughness of the road have become worse over the last five years.

The bituminous pavement along the whole of the Kaunisvaara-Pajala-Svappavaara road is quite thin and thickness varies from a few centimetres to twenty centimetres. The general pavement thickness is 35–45 mm. Longer thicker pavement sections could be seen only in Section 4 (Junosuando-Masugnsbyn) where it exceeded 200 mm thick in places. Pavement strain values were calculated from FWD data using Swedish bearing capacity formulas. The smallest (best) strain values were measured in the more recently built road Section 6 (Vittangi - Svappavaara), and the highest, and worst, strain values were measured in Sections 1 (Kaunisvaara - Pajala), and Section 2 (Pajala - Anttis). Even though strain values were high, pavement distress analyses showed that more than 90 % of the pavement was in reasonable condition with no visual damages. The biggest problems identified were longitudinal cracks and shoulder deformation.

Because of the varying construction and rehabilitation history of the road, the thickness of the unbound base course layers has great variation. The thinnest measured base course thickness was only a few centimetres and the thickest were more than half a metre thick. The base course is especially thick in sections where there are old steel nets. The total thickness of the pavement structure also had great variations, but generally the thickness comprised from 50 cm to 80 cm.

Laboratory analysis results revealed that a main problem with the road is the poor quality of the unbound base course material. Practically all of the base course samples had high fines content and adsorbed too much water and thus the base courses are likely to have permanent deformation problems during the spring thaw weakening period. The poor quality of the base course materials was also verified from the Surface Curvature Index values of the FWD data which showed that the SCI was generally higher than 250 μm , a value that can be observed as an alarm value for paved roads. A further problem is that, during the sampling, it was detected that in some sections there were remnants of old coal tar just below the pavement. The good news was that the steel net structures built in frost problem places is functioning quite well and that there is no significant damage in these sections.

Subgrade soils along the route varied from river sands and gravel to glacial moraine, silt and peat. Bedrock was present close to the road surface in a few locations only. The weakest subgrade soils could be found in road Section 1 (Kaunisvaara - Pajala), and Section 2 (Pajala - Anttis), where subgrade moduli in almost 20 % of the road section was less than 20 MPa. In these sections the calculated Odemark bearing capacity, based on FWD and GPR data, was less than 100 MPa, values that are normally found on forest roads. The good news was that there are no major geotechnical risks on the road.

The road cross section analysis, based on laser scanning and GPR data, showed that the road has both Mode 1 (related to upper part of road structures) and Mode 2 rutting problems (related to weak subgrade). The cross section data analysis also showed that the road shoulders are particularly weak and that there is permanent deformation taking place in the outer wheelpaths.

According to the data from the mobile laser scanner, the highest frost heave values are found in road Section 1 (Kaunisvaara – Pajala), where frost heave was mainly more than 120 mm and in some sections even more than 200 mm. In other road sections the frost heave is less with measured values varying from 40 mm to 120 mm. The smallest frost heave values were

unsurprisingly measured in the recently built road Section 6 (Vittangi – Svappavaara), where the majority of frost heave was less than 40 mm. Small frost heave values were also measured close to the river banks, where the subgrade is sand.

The current drainage condition of the Kaunisvaara-Svappavaara road is surprisingly good compared to similar roads in Northern Sweden and the results of the drainage analysis showed that Class 1 drainage condition could be seen in 60-90 % of the length of the road sections. In this analysis, Section 1 (Kaunisvaara – Pajala) was clearly the worst compared to any other section. The location of culverts with frost heave problems was also analysed and listed. The frost heave analysis showed that there were many frost heave issues that could be a result of poor drainage and clogged culverts below private road exits. A special drainage problem on the road is flooding close to the Torne river where a number of critical locations have had severe flooding problems in the past, resulting in the road being closed in places for several days over the last 20 years. It is obvious that these will appear again in the future.

As a part of the functional condition analysis of the road, a road geometry analysis was carried out to identify potentially problematic sections with steep hills and tight curves. Based on this analysis, it is proposed that climbing lanes should be built at two locations: Section 1 (Kaunisvaara – Pajala) from point 8900m to 10200m, and in Section 4 (Junosuando – Masugnsbyn) from point 86990m to 89090m. The horizontal geometry of the route was in general quite good and only one curve with a radius less than 200 m was detected. This was located in road Section 1 (Kaunisvaara – Pajala) between 17760 m and 18160 m. Based on experience from the local maintenance expert it is also proposed that the road horizontal geometry should be improved in Section 5 (Masugnsbyn – Vittangi) from point 118350m to 119750m for traffic safety reasons.

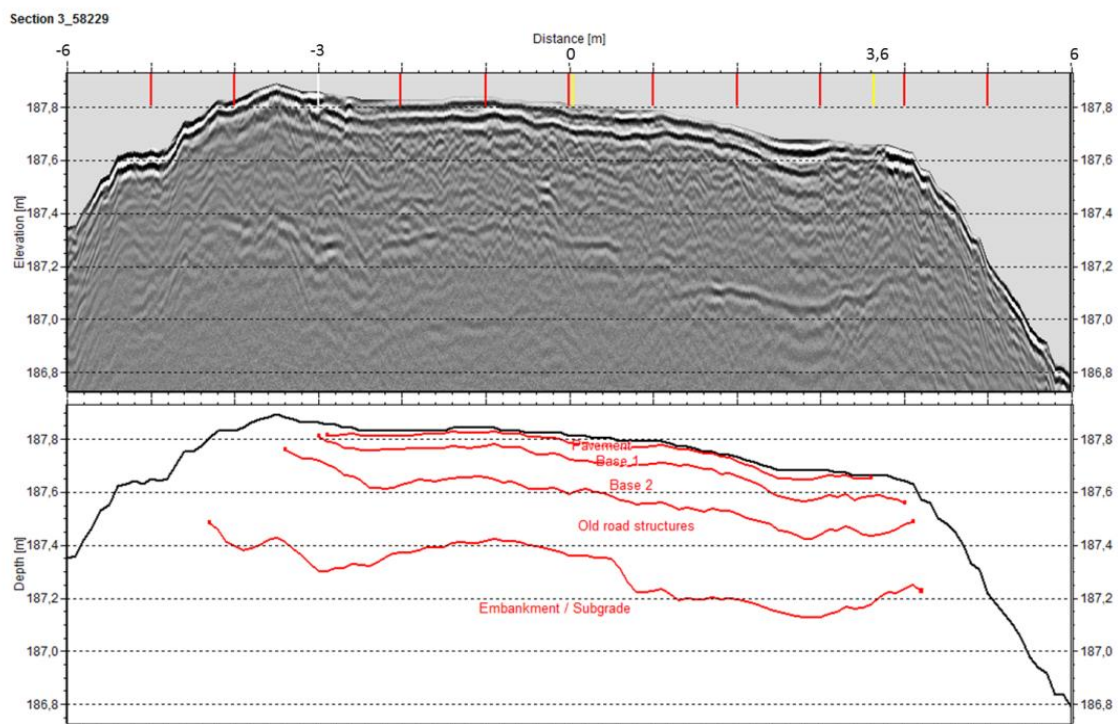


Figure 3.1. Example of a laser scanner and GPR cross section with severe mode 2 rutting problems in the right lane inner curve, Section 3, 58+620 m.

3.2. BRIDGES

The Kaunisvaara – Svappavaara road has 10 bridges in total, of which two are located on Road 99, six on Road 395, one on road E10, and one on Road E45. Table 3.1 gives a summary information of these bridges.

Table 3.1 Bridges on Kaunisvaara – Savappavaara road.

| Bridge type | Bridge | Construction year | Span[m] | Width[m] | Bearing capacity A/B [ton] |
|-----------------------------------|-----------|-------------------|----------------|----------|------------------------------------|
| Arch bridge | 25-139-1 | 1956 | 5,3 | 8 | 17/24, 17/33 |
| Arch bridge | 25-411-1 | - | 5,3 + 5,3 | 8 | 40/40, 40/75 |
| Slab frame bridge | 25-399-1 | 1969 | 12,5 | 7 | 20/25, 20/33,3 |
| Slab frame bridge | 25-403-1 | 1949 | 4,4 | 5,9 | 17/30, 17/40 |
| Slab frame bridge | 25-404-1 | 1949 | 7,4 | 5,9 | 17/27, 17/36 |
| Slab frame bridge | 25-409-1 | 1968 | 12,5 | 7,9 | 20/25, 20/33,3 |
| Slab frame bridge | 25-445-1 | 1961 | 15,5 | 7 | 20/23, 20/30,6 |
| Continuous steel beam bridge | 25-402-1 | 1964 | 33,3+2x34+33,4 | 7 | 14/19, 14/30,6 Classed by template |
| Culvert | 25-406-1 | 1972 | 3 | 7 | 12/20, 16/24 Generally classed |
| Continuous concrete girder bridge | 25-1261-1 | 1964 | 36,4+62+36,4 | 7 | 14/24, 14/32 Classed by template |

The condition of almost all of the bridges is currently good. No damages were recorded that would have an effect on bearing capacity. The only bridge with known problems is the Liukattijoki bridge, 25-411-1 (Figure 3.2). This bridge has already experienced movements in its arch elements, and increased heavy vehicle passes could have a negative impact on this bridge.



Figure 3.2. Bridge over Liukattijoki 4 km NW Svappavaara on Road E10

3.3. HUMAN SETTLEMENT

There are numerous houses and villages near the Kaunisvaara – Pajala – Svappavaara road which have to be considered when evaluating the impact of transport on local human settlement. The main issues in this will be noise and vibration caused by heavy trucks. The most important settlements, and their location from the beginning of the project, are listed below:

- Kaunisvaara village (1800-2420m),
- Vaararinta village (3870-4300m),
- Sahavaara village (4800-5250m),
- Autio village (21000-21340m),
- Erkheikki village (21900-22720m),
- Juhonpieti village (23850-24200m),
- Pajala airport (27700-28100m),
- Anttis village (42550-44200m),
- Lovikka village (54400-55500m, 55950-56600m, 57100-58000m),
- Huhtanen village (59100-60450m),
- Torneforss village (65900-66120m, 67000-67180m, 67400-67600m),
- Junosuando village (67900-68100m, 68600-71600m),
- Kero village (80700-81000m),
- Masugnsbyn village (89300-92250m),
- Merasjärvi village (103050-103800m),
- Vittangi village (120150-124450m) and
- Svappavaara village (151300-151600m, 152750-153000m).



Figure 3.3. Heavy haulage will most likely cause some noise and vibration problems for local houses. Vittangi is the largest settlement on the transportation route. A point cloud model (as shown) will help with the evaluation of risks.

5. IMPACT ANALYSIS AND MEASURES NEEDED

5.1 LIFETIME ANALYSIS FOR ROADS

The calculations of remaining lifetime, assuming that heavy haulage starts on the current road, were made using Swedish PMS-object software. In these calculations the road was divided into subsections based on the evaluations of the quality of subgrade soil, structure thicknesses based on the GPR data, drill cores and FWD data. In the adjusted calculations an examination was made separately for each risk class (see Chapter 2.1). It should be kept in mind that PMS Objekt software assumes that only standard 60 tonne trucks are used in the haulage.

The results showed clearly that, if and when the heavy haulage starts on the current road without strengthening, the remaining lifetime of the road pavement will be very short and that 96 % of the road length will have serious problems within the first year. With the bound layers, the remaining lifetime is less than 1 year, except in Section 4 (Junosuando – Masugnsbyn), in risk class 2 where it is one year. At the foundation level the remaining lifetime varies between 0-8 years and mainly it is 1-2 years.

5.2. NEED FOR ROAD STRENGTHENING AND OTHER IMPROVEMENTS

Structural solutions were designed and tested based on PMS Objekt software with the aim of designing a structure with a lifetime of 20 years. This analysis showed the importance of having a 200 mm bound layer thickness on top of the new structure. Using a 150 mm bound layer thickness gave only a 6-8 year lifetime for the new structure.

Based on the evaluations of numerous structural options, three main structural solutions were selected with practically all having 200mm of bound layers on top. The only exceptions to this are the sections that are planned to have a third lane, where the old road will be used mainly by empty trucks. These sections can have 100mm of bound layers. The most general solution proposed is to add new layers (unbound base and bound layers) on the top of the existing road layers after the old pavement has been removed and the old unbound base surface has been shaped.

The strengthening of the old road over weak subgrades proved to be difficult. It is recommended that in these weakest sections (mostly risk Class 5), that a third lane should be built for the heavy trucks. In these sections savings can still be achieved as the old road will not be so heavily strengthened: i.e. the new structure will comprise a 100mm bound layer and 100mm unbound layer on the top of the old road. In the extremely weak sections (peat areas) with potential pumping problems it is recommended that steelnets should be used.

The cost estimate for the rehabilitation work is **377 mill SEK**, including:

- materials and work for road strengthening (pavement, bound base, unbound base, sub base, filter sand)
- excavations, geotextiles, steelnets
- drainage improvement (ditching)
- slope fillings
- removal of old pavement
- construction of 2 climbing lanes
- improvement of road geometry in one section

Road widening from the existing width is not included in estimated costs, neither are unexpected costs nor the cost of project management.

5.3 ANALYSIS OF HEAVIER HAULAGE OPTIONS

The Bisar software comparison calculations of the different truck options showed that induced subgrade displacement was lowest for the standard 60 tonne truck, but the 72 tonne and 90 tonne options were not much worse. The "Double link" options with four axle groups were somewhat worse, but, when compared with each other, there was not a great difference between them.

However bigger differences could be detected when cumulative subgrade displacement calculations were made for each of the truck options. On the basis of the cumulative subgrade displacement evaluation (Figure 5.1), the 60 tonne option was again the best. The 72 and the 90 tonne options were approximately on the same displacement level with each other with maximum cumulative displacement of 1.0 – 1.5 mm (approximately 30 - 40 %) greater than the 60 tonne option. The "Double link" options were again the worst, with maximum cumulated displacements between 6.5 mm and 7.5 mm, which are more than 2 times higher compared to a standard 60 tonne truck. It should also be noted that the calculated cumulative subgrade displacement for the heaviest cases represent an optimistic / conservative estimate because the subgrade recovery in real life is not as immediate as the Bisar® calculations indicate. This is due, for example, to the development of excess pore water pressures and in real terms the cumulative effect could, in unfavourable conditions, be even stronger.

The distance between axle groups in the combination should be at least 3 metres. A distance greater than 3 metres does not have a major effect on elastic response, only on recovery times.

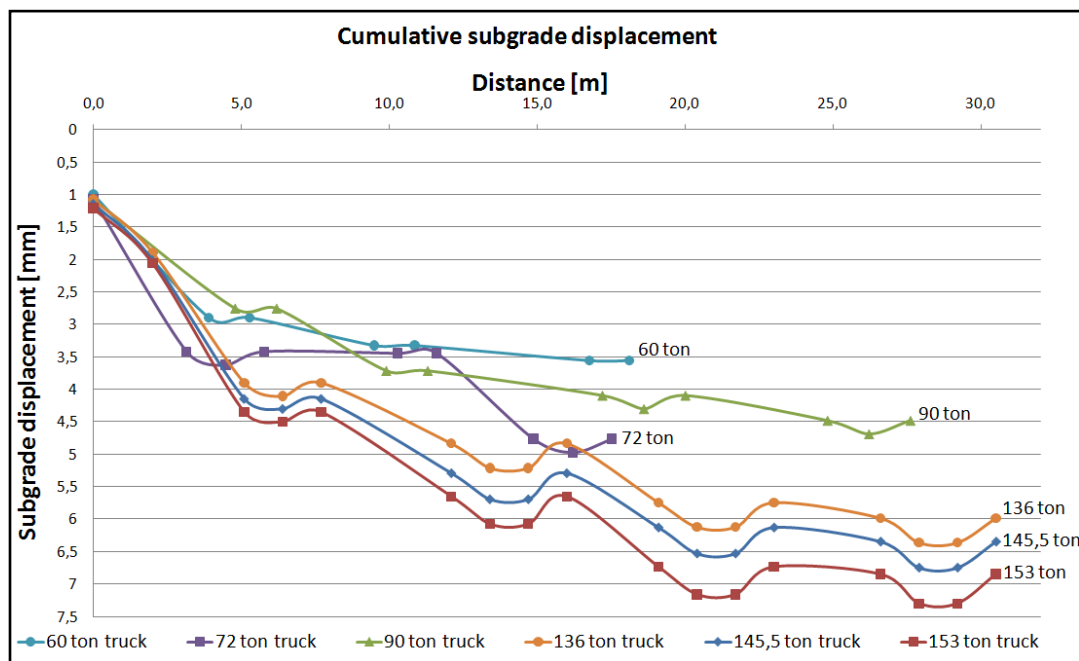


Figure 5.1. Cumulative displacement of a weak subgrade (modulus 10 MPa) calculated for each truck option. The horizontal axis presents the distance from the first axle of the truck. Zero is the first axle and the dots along the displacement curve present the locations of the consecutive axles. The vertical axis shows the cumulative subgrade displacement calculated at one point.

In addition to displacement calculations with the Bisar® software, another separate comparison of the truck options was also developed based on the classical 'fourth power rule' used in pavement engineering. This rule slightly underestimates rutting and overestimates pavement distress but in general is still quite reliable in estimating pavement performance under different loadings.

The results of the fourth power rule calculations are given in Table 5.2. The value in the last column is the comparison factor relative to a standard 60 tonne truck and shows that, based on this assessment, all truck options are better than the standard 60 tonne truck. For example, the

"Boliden" 72 tonne truck is 27 % better than the 60 tonne option according to the calculation. The best option in the evaluation was the 136 tonne double link. The values less than 0.75 are highlighted in green representing the best options. The values greater than 0.75 but less than 1 are highlighted in yellow representing moderate options.

Table 5.2. The results of the 'fourth power rule' calculations on the effect of different trucks on pavement performance

| Truck option & total weight | Axel loads | | | | | Truck EKV | Net weight [ton] | Truck loads | Load effect | Comparison to 60 ton |
|--|------------|-------|---------|-------|---------|-----------|------------------|-------------|-------------|----------------------|
| | 7,5 ton | 8 ton | 8,5 ton | 9 ton | 9,5 ton | | | | | |
| Standard 60 ton | 1 | 2 | 0 | 3 | 1 | 3,918 | 38 | 131579 | 515581 | 1 |
| "Boliden" 72 ton | 0 | 9 | 0 | 0 | 0 | 3,686 | 49 | 102041 | 376163 | 0,730 |
| "ETT (En travé till)" 90 ton | 0 | 7 | 0 | 4 | 0 | 5,492 | 60 | 83333 | 457633 | 0,888 |
| "Double link" 136 ton | 0 | 17 | 0 | 0 | 0 | 6,963 | 109 | 45872 | 319413 | 0,620 |
| "Double link" 145,5 ton | 0 | 0 | 15 | 2 | 0 | 9,142 | 118,5 | 42194 | 385751 | 0,748 |
| "Double link" 153 ton | 0 | 0 | 0 | 17 | 0 | 11,154 | 126 | 39683 | 442607 | 0,858 |
| Annual transportation (ton) = | | | | | | | | | | |
| | | | 5000000 | | | | | | | |
| Stress exponent used in calculations = | | | 4 | | | | | | | |

The evaluation of road recovery time after the passing of each truck proved to be the most challenging issue in the impact analysis. Recovery times were evaluated by the delay times of KUAB HWD measurements from time history data, which can be considered as minimum recovery time but not the maximum. Data analysis results showed that long delay times can be expected to take place in risk Class 5 with low subgrade moduli values. Based on the results from cumulative deflection modelling in Figure 5.1, the minimum calculated delay time and distance for a heavy truck driving at 80 km/h is roughly 1.5 seconds and 30-40 metres. A long road recovery time will increase the effect of heavy trucks, and the risk that positive pore water pressures will develop. Heavier trucks will however allow the time interval between the trucks to be correspondingly longer than lighter trucks, and so allow longer time for the road to recover, i.e. five minutes in practice, or roughly 200 times longer than the calculated recovery period. The distance between trucks has to be controlled however and convoy driving must be strictly forbidden.

The extra cost for road strengthening if heavier trucks are to be used was also calculated. In these calculations the "normal" rehabilitation measures designed for the 60 tonne truck were also enough for the 72 tonne and 90 tonne options. The calculated additional base course thickness needed for double link options was approximately 250 mm and this additional thickness was calculated only for the road sections with risk Class 4 or 5, excluding the sections where the third lane will be used. The total cost estimate for this extra work is approximately **12.5 million SEK**. Unexpected costs and the cost of project management are not included.

5.4 RESULTS OF BRIDGE ANALYSIS

Calculations were carried out on the impact of the different truck options on the failure stage and strength against fatigue for most of the bridges.

The slab frame bridge calculations showed that in bridge 25-445-1, the bridge deck close to the frame leg had insufficient strength against fatigue with regard to shear. Other similar bridges were sufficient for all the loading options.

The calculation results for the concrete girder bridge showed that truck options of 60, 72 and 90 tonne were within the capacity of the bridge, but the heavier trucks exceeded it. A practical solution for the heavier trucks in this situation is for the heavy vehicle to drive in the middle of the bridge at a maximum speed of 40 km/h. No other traffic would be allowed to use the bridge at the same time as the truck. Using this solution the bridge can be loaded for a maximum of 4 years.

The worst calculation results concerned the continuous steel beam bridge, where fatigue calculations indicated failures even with the standard 60 tonne options. In the longitudinal direction the critical feature was local buckling of the main beam web and high fatigue stress ranges. In the transverse direction the lack of capacity was due to an insufficient amount of top reinforcement in the bridge deck, and an insufficient amount of bottom reinforcement in the bridge deck between the longitudinal steel beams. This bridge can only be crossed at a very slow speed.

Proposals for mitigation measures at the bridges, together with their respective estimated costs are summarised below:

Slab frame bridges:

- Reinforcement of the haunches of the bridge deck by on-casting. The estimated cost is 300,000 SEK. There may also be a further requirement to strengthen other slab frame bridges which have not yet been checked.

Prestressed reinforced concrete girder bridge:

- Additional calculations are needed to determine if it is technically possible to reinforce the longitudinal concrete girders at a reasonable cost to enable the 126 – 153 tonnes vehicles to cross the bridge. There may also be a need for material sampling and measurements.
- The fatigue check of the bridge deck in the transverse direction might also require a need for reinforcement.
- If the reinforcement measures turn out to be unacceptable an alternative measure is to replace the bridge superstructure, assuming that the bridge substructure and foundation have sufficient capacity. The estimated cost for this measure is approximately 30 million SEK. A further option is to build a new bridge.
- Until the bridge strengthening measures can be done, i.e. within a maximum of 4 years, a heavy vehicle can be driven along the middle of the bridge with restrictions.

The steel beam bridge

- Strengthening is not considered to be technically or economically reasonable for this bridge. Instead it is proposed that the superstructure of the bridge is replaced, assuming that the substructure and the foundation have adequate capacity. The cost for this is estimated to be about 30 million SEK. An alternative option is to build a new bridge.
- Until the bridge superstructure can be replaced, within a maximum of 4 years, heavy vehicles can drive along the middle of the bridge with some restrictions. Measures to make this possible may involve a cost of about 2 million SEK. Further calculations are necessary to confirm what needs to be done. There may also be a need for measurements and material tests.
- 90 tonnes is the maximum weight of truck that is allowed on the steel beam bridge until actions have been taken, e.g. a new bridge.

The culvert

- An assessment of the culvert is essential to determine if the bearing capacity is sufficient to carry the proposed vehicles. The cost of a replacement culvert is estimated at approximately 2.5 million SEK.

The arch bridges

Bridge 25-139-1

- An evaluation of the fatigue capacity of this bridge is required. The cost of a replacement bridge is estimated at approximately 3 million SEK.

Bridge 25-411-1

- Heavy vehicles may lead to increased movements in the arch elements of this bridge thereby affecting the overall bearing capacity of the bridge. A replacement may be needed, replacing the two existing arches with a new structure. The costs for this will be approximately 7 million SEK.

If the steel beam bridge is removed from the above considerations the results of the calculations done so far show that a maximum vehicle weight of 90 tonnes may be permissible. Truck options with a total weight of 153 tonnes can also be accepted as a temporary measure for 4 years. After that the prestressed reinforced bridge will require restrictions. Vehicles with weights more than 90 tonnes will then only be allowed to drive along the middle of the prestressed reinforced bridge.

For the steel beam bridge loadings by 90 tonne vehicles will be permissible for 4 years. Following this period, the vehicle will have to be driven along the middle of the bridge. Reinforcement of the steel beam bridge may be necessary to permit this.

For the other bridges only minor measures will be needed to allow trafficking by 153 tonnes vehicles. At worst, a replacement of the culvert and the two arch bridges may be necessary.

Table 5.3 summarises the estimated bridge strengthening costs for each truck option.

Table 5.3 Bridge strengthening costs for different truck options

| truck option | 60 tn | 72 tn | 90 tn | 136 tn | 146 tn | 153 tn |
|-----------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| costs mill SEK | 36 | 39 | 39 | 69 | 69 | 69 |

5.5 RESULTS OF THE NOISE ANALYSIS

The noise analysis carried out in the project included: calculation of the number of houses in the noise area, estimation of noise reduction measures needed and their price. The following default values were used in calculating the costs:

- Window measure: 80,000 SEK/house
- Noise wall: 2,700 SEK/m² (2 m height supposed)
- Patio: 50,000 SEK/each

A summary of the noise analysis results is presented in Table 5.4 for the >70 dBA maximum noise area, and in Table 5.5 for the >80 dBA maximum noise area. In the >70 dBA maximum noise area a total of approximately 170 houses have been identified and of these it is calculated that 66 will require noise walls and 104 will need window improvements. The total cost for these measures is approximately **32 mill SEK**. Unexpected costs and the cost of project management are not included in the prices.

Table 5.4. A summary of the objects, noise reduction measures required and their costs in the >70dBA maximum area in the Pajala mine road.

| Measure | Number/length | Cost, mill SEK |
|----------------|---------------|----------------|
| Windows | 104 pieces | 8.3 |
| Walls | 3500 m | 19.0 |
| Patios | 89 pieces | 4.5 |
| | | 31.8 |

Altogether, 29 houses were located inside the >80dBA maximum noise area. The total cost for the different noise measures listed is approximately **5.4 mill SEK**. Unexpected costs and the cost of project management are not included in the prices.

Table 5.5. A summary of the objects, noise reduction measures needed and their costs in the >80dBA maximum area in the Pajala mine road.

| Measure | Number/length | Cost, mill SEK |
|----------------|---------------|----------------|
| Windows | 18 pieces | 1.4 |
| Walls | 600 m | 3.2 |
| Patios | 15 pieces | 0.8 |
| | | 5.4 |

6. SOCIO-ECONOMIC ANALYSIS OF DIFFERENT TRANSPORT OPTIONS

Table 6.1 presents the socio-economic investment costs where a tax factor (21%) has been added along with an index figure (0.91) to make the costs comparable with the evaluated effects from EVA, which uses a price level from year 2006. It shows that the greatest part of the investments is needed for road strengthening.

Table 6.1. Socio-economic investment costs for proposed infrastructure for the different vehicle configurations (väg=road, bro=bridges, buller=noise) in mill SEK at 2006 prices

| Samhällsekonomisk investeringskostnad. Prisnivå 2006-medel, Mkr | | | | | | |
|---|-----------|-----------|-----------|------------|------------|------------|
| | Konfig 60 | Konfig 72 | Konfig 90 | Konfig 136 | Konfig 146 | Konfig 153 |
| Väg | 412 | 412 | 412 | 426 | 426 | 426 |
| Bro | 40 | 43 | 43 | 76 | 76 | 76 |
| Buller | 41 | 41 | 41 | 41 | 41 | 41 |
| Summa investering | 493 | 496 | 496 | 543 | 543 | 543 |

Table 6.2 summarises the results of calculations into the effects on traffic operations for each of the vehicle configurations respectively. The values in the table are monetary estimates of the traffic operational effects over one year. The delay effects for trucks and personal cars are small and are not included in the table. A supplementary analysis using very high volumes of trucks on the road sections, shows that the volumes will have no effects on other traffic. The explanation is the relatively low traffic volumes on the section. This is supported by calculations from EVA. The table illustrates that the biggest effects are for vehicle operation costs, travel time costs, accident costs and environment costs. These are valid for all of the vehicle configurations considered.

Table 6.2. Estimated costs of the effects on traffic operation for the different vehicle configurations (personbil=passenger car, lastbil=trucks) for the starting year. The estimations in EVA are at 2006 price levels.

| | Värderade effekter (MKr) | | | | | |
|--------------------------------|--------------------------|-----------|-----------|------------|------------|------------|
| | Konfig 60 | Konfig 72 | Konfig 90 | Konfig 136 | Konfig 146 | Konfig 153 |
| Restidskostnader | 464 | 427 | 397 | 356 | 351 | 348 |
| <i>Varav personbil</i> | 266 | 265 | 265 | 264 | 264 | 264 |
| <i>Varav lastbil</i> | 199 | 162 | 132 | 92 | 87 | 84 |
| Fordonskostnader | 524 | 508 | 500 | 497 | 504 | 503 |
| <i>Varav drivmedel</i> | 127 | 114 | 108 | 94 | 93 | 93 |
| <i>Varav personbil</i> | 125 | 126 | 126 | 126 | 126 | 126 |
| <i>Varav lastbil</i> | 272 | 268 | 266 | 277 | 285 | 239 |
| Godskostnader | 31 | 25 | 20 | 13 | 12 | 12 |
| Olyckskostnader | 149 | 136 | 126 | 112 | 110 | 109 |
| Miljökostnader | 126 | 111 | 102 | 85 | 83 | 83 |
| <i>varav kväveoxider, NOX</i> | 28 | 23 | 19 | 13 | 13 | 12 |
| <i>varav kolväten, HC</i> | 2 | 2 | 2 | 2 | 2 | 2 |
| <i>varav koldioxid, CO2</i> | 96 | 86 | 81 | 70 | 69 | 68 |
| <i>varav svaveldioxid, SO2</i> | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>varav partiklar</i> | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 |
| Summa: | 1295 | 1206 | 1143 | 1063 | 1061 | 1054 |
| DoU kostnader, Mkr | 36 | 35 | 34 | 34 | 33 | 33 |
| Summa totalt: | 1330 | 1241 | 1178 | 1096 | 1094 | 1088 |

Table 6.3 presents the gross values for the traffic operations and investment costs for each truck option at 2006 prices.

Table 6.3. Total traffic operation and socio-economic investment cost for each vehicle configuration respectively at 2006 prices.

| | Bruttovärden trafikerings-och investeringskostnader | | | | | |
|--------------------|---|-----------|-----------|-----------|------------|------------|
| | Konfig 60 | Konfig 72 | Konfig 90 | Konfig136 | Konfig 146 | Konfig 153 |
| Trafikering | 1330 | 1241 | 1178 | 1096 | 1094 | 1088 |
| Investering | 493 | 496 | 496 | 543 | 543 | 543 |

Table 6.4 compares the truck options for 72, 90, 136, 146 and 153 tonnes in relation to the standard 60 tonne truck (i.e. traffic operation effects and investments for the heavier configurations when the values for the 60 tonnes vehicle have been subtracted). The 'net value for Year 1' is given. The net value for year 1 is the traffic operation gain made by using vehicles with bigger load weights compared to 60 tonne vehicles, minus the investment costs that each vehicle configuration requires to be able to traffic the section. The net value is a comparison figure for determining which of the vehicle configurations are the most suitable as mining transports.

Table 6.4 Net values for each heavy vehicle configuration compared to a 60 tonnes vehicle.

| | Nettovärden trafikerings-och investeringskostnader | | | | |
|---|--|-----------|------------|------------|------------|
| | 72 rel 60 | 90 rel 60 | 136 rel 60 | 146 rel 60 | 153 rel 60 |
| S:a trafikering, netto | 89 | 152 | 234 | 236 | 242 |
| S:a sam.h. ek investering, netto | 3 | 3 | 51 | 51 | 51 |
| Nettovärde År 1 | 86 | 149 | 183 | 185 | 191 |

A similar calculation was made for the net present value for 10 years of mining transports. The results of these analyses show that the relationships between the vehicle configurations do not change, even when the additional values of the investments are taken into account.

An analysis of the ore transports' proportion of the total traffic was made by comparing the traffic operation effects generated by the truck traffic today, against the traffic operation effects generated by the mining transports. Table 6.5 summarises the percentage proportion of the total traffic originating from the mining transports for each vehicle configuration respectively.

Table 6.5 Mining transports' proportion of total travel time effects, vehicle operation costs and goods costs for truck traffic for each vehicle configuration respectively.

| | Gruvtransporternas andel av värderade effekter | | | | | |
|-------------------------|--|-----------|-----------|-----------|------------|------------|
| | Konfig 60 | Konfig 72 | Konfig 90 | Konfig136 | Konfig 146 | Konfig 153 |
| Restidskostnader | 81% | 77% | 72% | 60% | 57% | 56% |
| Fordonskostnader | 87% | 84% | 81% | 74% | 73% | 72% |
| Godskostnader | 88% | 85% | 82% | 72% | 70% | 69% |

These results show that it is more profitable to carry out ore transport with heavier vehicles rather than 60 tonnes vehicles when considering investment and traffic operation costs. The Table also shows that ore transports are likely to generate about 60% - 90% of the traffic operation costs of total truck traffic.

7. CONCLUSIONS

An impact analysis of the Kaunisvaara – Pajala – Svappavaara road was carried out first using PMS Object calculations. This showed that 96 % of the road will have failures within one year after heavy haulage starts and that major strengthening measures will require to be done in 2012.

The PMS Object calculations also showed that a basic strengthening structure for 20 years of service life should consist of 50 mm of bituminous wearing course, 150 mm of bituminous bound base and 100 – 350 mm of unbound base. In addition it is recommended in many cases that a new lane for heavy trucks should be built in the weakest sections. This new lane would act as passing place for other cars. In those sections, where a third lane cannot be built, it is recommended that soil replacement structures should be used, and in some sections raising the gradeline is an option. In addition to the new third lanes it is also recommended that at least two climbing lanes are built on the steepest hills of the road. Horizontal geometry of one section should also be improved due to traffic safety issues. All of the road intersections should be redesigned and acceleration lanes for heavy trucks should be considered wherever it is possible. Frost heave analysis showed that there were only a few places where bearing capacity dimensioning was not enough for the frost heave. The structures for these sections should be designed on a case-by-case basis.

Road drainage along the route is in general in relatively good condition but still it is recommended that the drainage of the whole road should be improved to drainage Class 1 before strengthening works are undertaken. Culverts and transition wedges with frost issues should be repaired or changed. In addition analysis of the data from mobile laser scanning has shown that clogged, frozen or missing private road culverts can have a great impact on road performance. Such culverts should be checked and fixed, as poor road sections will cause major vibration problems to houses close by.

The total cost estimate of the basic road rehabilitation is 377 mill SEK for 60 tonne trucks. If heavier trucks are to be used, the estimated extra costs for strengthening would be 12.5 mill SEK. This cost estimate does not cover possible road widening and measures on four sections with major flooding risks. Unexpected costs and the cost of project management are not included in the costs presented and neither are the costs for rehabilitation of the bridges and traffic safety.

Throughout the impact analysis process more than 30 different truck options, suggested by the mining company and different truck manufacturers, have been evaluated. Calculations undertaken showed that CTI does not help in the project as thick bound layers will be used. The most critical sections will be those sections with weak subgrades (10 MPa), and these sections will be especially weak during the spring thaw. Calculations also showed that the displacement in the subgrade with heavier truck configurations can be two times higher in comparison to a normal 60 tonne truck. This is a serious risk that everyone should be aware of if heavier truck options are used. On the other hand, the cumulative load impact of these heavier trucks on the pavement is much less than if haulage was done using standard 60 tonne trucks.

Recovery time measurements and calculations showed that road recovery will be an issue especially in the road sections with Class 5 problems. Positive pore water pressures will be generated under repeated axle loads and these will reduce the stiffness of the subgrade further. Calculations of different truck options showed that heavier truck options than 100 tonnes will need longer recovery times, but this will be the case anyway if heavier trucks are used and the distance between trucks is controlled. If, on the other hand, most of the Class 5 risk class sections are replaced with well designed and constructed 'third lanes', recovery times will not be an issue when heavy haulage starts.

This analysis project did not, however, solve all of the questions with regard to road performance and, as such, it is recommended that structural monitoring should be done when the full scale tests

are conducted in the Fall of 2011. In addition, a sufficient number of sensors should be installed in the new road so that the road performance can be monitored continuously, and a routine road monitoring system designed to support preventative maintenance actions on the road. In other words, potential failures should be detected before they occur. A special winter maintenance plan should also be made to ensure that the operational trucks do not get stuck on slippery and steep hills during snow storms.

The bridge analysis results showed that most of the bridges on the route are relatively strong and capable of carrying the loads of even the heaviest haulage options. However the prestressed concrete girder bridge over the Torne River and the steel beam bridge over the Tärendo River should only be used for a maximum of 4 years. The strengthening costs, or cost of building a new bridge, are estimated at 30 mill SEK each. Other bridges will need lesser works.

It is likely that the Swedish target values for noise in respect of new construction and substantial rehabilitation of road infrastructures will be applied on this project. This means that all houses with a noise level >70 dBA will require to have noise protection. The noise analyses carried out under the project identified approximately 170 houses within this noise level. The costs for the noise protection measures for these houses were calculated to be approximately 32 mill SEK.

Finally the results of a traffic economic analysis using all of the analysed information mentioned, showed clearly that all of the truck options heavier than the standard 60 tonne trucks would be more profitable when using socio-economic calculations. The socio-economic costs varied from 1,330 million SEK when using standard 60 tonne trucks, down to 1,088 million SEK when using the 153 tonne 'double link' option. The theoretical annual operator gains for heavier truck options varied from 86 million SEK when using the 72 tonne truck, up to 191 million SEK when using the 153 ton truck options. The differences between the costs and benefits for the different double link options (136 tonnes, 146 tonnes and 153 tonnes) were not big.

ROADEX PROJECT REPORTS (1998–2012)

This report is one of a suite of reports and case studies on the management of low volume roads produced by the ROADEX project over the period 1998-2012. These reports cover a wide range of topics as below.

- Climate change adaptation
- Cost savings and benefits accruing to ROADEX technologies
- Dealing with bearing capacity problems on low volume roads constructed on peat
- Design and repair of roads suffering from spring thaw weakening
- Drainage guidelines
- Environmental guidelines & checklist
- Forest road policies
- Generation of 'snow smoke' behind heavy vehicles
- Health issues raised by poorly maintained road networks
- Managing drainage on low volume roads
- Managing peat related problems on low volume roads
- Managing permanent deformation in low volume roads
- Managing spring thaw weakening on low volume roads
- Monitoring low volume roads
- New survey techniques in drainage evaluation
- Permanent deformation, from theory to practice
- Risk analyses on low volume roads
- Road condition management of low volume roads
- Road friendly vehicles & tyre pressure control
- Road widening guidelines
- Socio-economic impacts of road conditions on low volume roads
- Structural innovations for low volume roads
- Treatment of moisture susceptible materials
- Tyre pressure control on timber haulage vehicles
- Understanding low volume pavement response to heavy traffic loading
- User perspectives on the road service level in ROADEX areas
- Vehicle and human vibration due to road condition
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