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Longevity chart for planning production and the renovation of orepasses

W Sredniawa *Luleå University of Technology, Sweden*

B Skawina *Luleå University of Technology, and LKAB, Sweden*

J Rapp *LKAB, Sweden*

G Shekhar *LKAB, Sweden*

J Gunillasson *LKAB, Sweden*

Abstract

Orepasses are used in rock mass transportation systems to transport the material to lower levels. If the ability to transport the material is lost, the failed orepass can be restored, but the process is usually costly, and the time to restore the orepass is usually long, possibly resulting in disturbances in material flow. This study introduced a longevity chart to plan for the availability and renovation of orepasses. A longevity chart is based on the orepass parameters, such as geotechnical conditions, stress and strength regimes, design parameters, and operational procedures. It guides mine planners in the creation of future production plans and renovation plans for the orepasses. The study presented in this paper was based on the Luossavaara-Kiirunavaara Aktiebolag Kiirunavaara sublevel caving mine located in the northern part of Sweden. This paper explains the creation process of the longevity chart and its implementation in renovation plans.

Keywords: *orepasses, longevity chart, production planning, renovation*

1 Introduction

In underground mines, typical underground transportation systems consist of hoists, conveyors, orepasses, roadheaders, loaders, trucks and even trains. Any disruption of the dynamics of the material flow in the given transportation system may require the material to be diverted to another transportation system. Each of these systems operates within its specific capacity, and depending on the configuration, it also interacts with other transportation systems. Orepasses are a commonly used transportation system whereby material is transferred from a higher level to a lower level by gravity. Their failure creates a significant risk of production disturbances (Brummer 1998), as there is no effective strategy for quickly restoring and maintaining the operational capacity of the area. Therefore, the loss of an orepass is a problem and often leads to long-term reductions in operational capacity (Skawina et al. 2018). Poor design, poor fragmentation, and caving often cause orepass stoppages (Beus et al. 2001) due to orepass blockages, piping, hang-ups, wall stability issues, and orepass degradation (Beus et al. 2001; Hadjigeorgiou & Lessard 2010). Adverse ground conditions can be caused by a combination of various factors such as stress regime, rock mass quality, major structure, and orepass orientation with respect to major joint sets or bedding which have the main impact on orepass longevity (Hadjigeorgiou & Mercier-Langevin 2008), and if the ground conditions are very poor, even the combined effect of the best liner and the best ground support cannot overcome their impact (Hadjigeorgiou & Mercier-Langevin 2008). The orepass location should be investigated before its development (i.e. locating it in the best ground conditions) via core drilling parallel to the planned orepass and as close to it as possible. Orepasses should not be in clay or heavily fractured areas. To avoid induced stresses from production voids, orepasses should be located farther away from the hanging wall and deeper into the footwall (Sjöberg et al. 2003). Finally, the quality of the rock mass in which the orepass is located is extremely important from a geotechnical point of view, and the best possible rock mass quality should be selected.

2 Kiirunavaara case study

This paper presents part of a longevity chart study in Luossavaara-Kiirunavaara Aktiebolag Kiirunavaara's (LKAB) Kiirunavaara Mine located in the northern part of Sweden. Footwall rock types in Kiirunavaara Mine are classified as skarn, granite, and trachyte-trachyandesite (referred to as syenite porphyries). Some of the rock mass is significantly altered, resulting in reduced rock mass quality (Berglund & Andersson 2013; Vatcher et al. 2016). The mine uses the sublevel caving method to extract the iron ore. The orebody is approximately 4 km long, with an average thickness of 80 m and unknown depth. The mine is currently divided into 10 separate production areas with a total of 37 orepasses (Figure 1). Each production area has its own orepass group, and depending on the thickness of the orebody, two to four orepasses are assigned to the area and spaced 30–50 m apart. Orepasses are grouped together and connected to the TappGrupp (TG) systems located at the bottom of the orepasses. Other shafts within the orepass groups include ventilation rises running closer to the footwall. The orepasses in Kiirunavaara Mine run from the 1,022 m level down to the main haulage level at 1,365 m, at approximately 60°. The orepasses studied are located in TG26 (Op_1 to Op_4) and TG30 (Op_5 to Op_8) in the southern part of the mine (Figure 1).

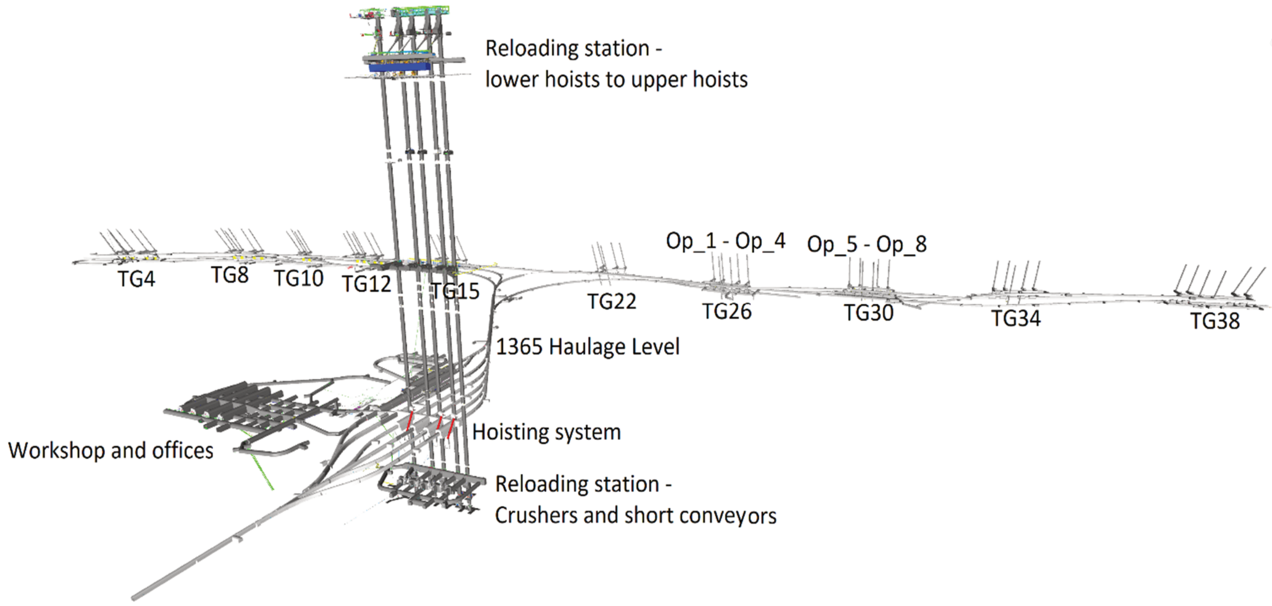


Figure 1 1365 – main haulage level in Kiirunavaara Mine

2.1 Orepass structure

The design diameter of an orepass is 3 m with a length of approximately 300 m reamed in three sections: 1,020–1,165 m, 1,165–1,252 m, and 1,252–1,338 m. The orepass is divided into sections because of the length of the reamer. This also allows rehabilitation and inspection of a particular section instead of the full length of the orepass. Figure 2 shows a schematic of a typical orepass in Kiirunavaara Mine, including transition zones where inspection drifts are located.

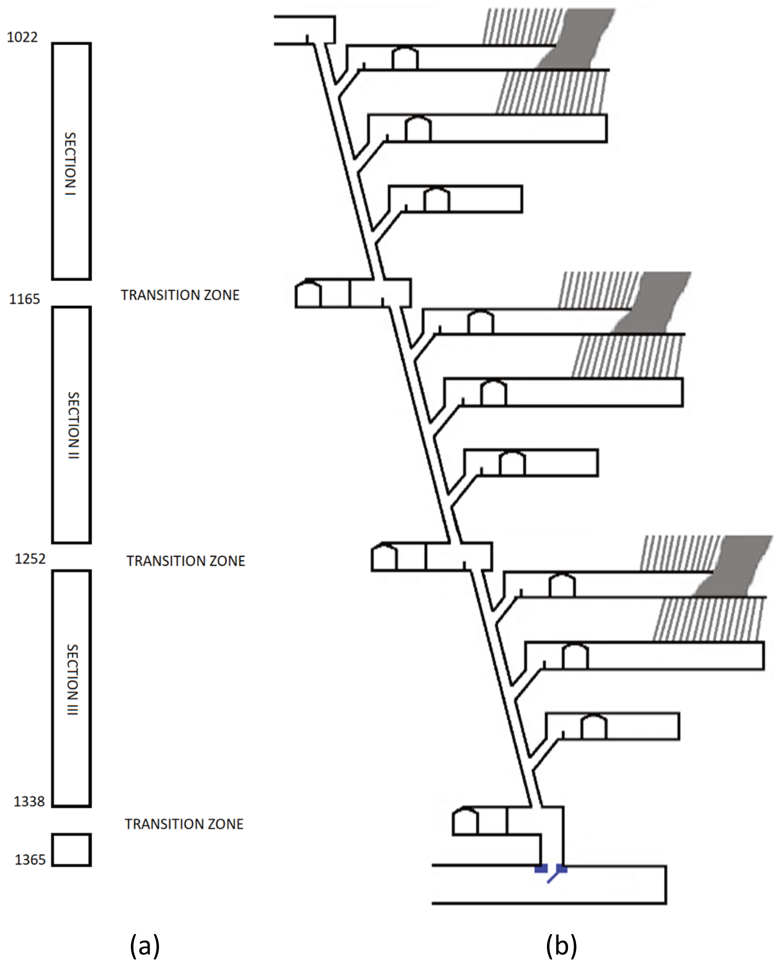


Figure 2 Orepass schematic of Kiirunavaara Mine, divided into sections. (a) Front view; (b) Side view

From the production levels, the material is hauled and dumped via load–haul–dump (LHD) machines into the finger raises (Figure 3). The finger raises are angled to reduce the impact of the material striking the orepass walls. Trains transport the material from the bottom of the orepasses to the crusher, where it is reloaded into the skip and hoisted up to the surface.

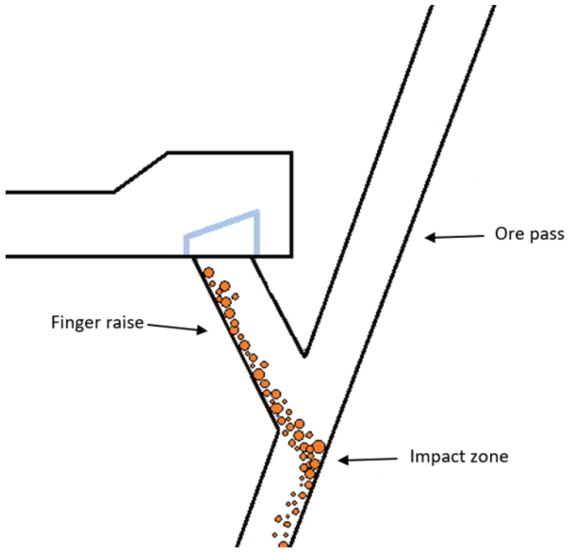


Figure 3 Finger raise zone

3 Orepass longevity chart

The longevity chart is an extension of the orepass longevity index function presented by Hadjigeorgiou and Mercier-Langevin (2008):

$$Orepass\ Longevity = Adjustment\ Factor \times LRF \times LEF \quad (1)$$

where:

LRF = Longevity reduction factor.

LEF = Longevity extension factor.

The orepass longevity function is a combination of the following factors: the longevity reduction factor, longevity extension factor, and adjustment factor. The longevity reduction factor consists of the following: adverse ground condition factors (stress regime, rock mass quality, major structure, and orepass orientation with respect to the major joint set or bedding), wall impact factors (material size and presence of fingers/knuckles), and orepass operation factors (blasting to restore flow and cushion guidelines). The longevity extension factor is related to ground support and liners, whereas the adjustment factor depends on the historical behaviour of the orepass.

3.1 Data collection and input

The information collected consisted of the current information on production, damage mapping, tunnel condition index, production levels, rock support, cushion guidelines, transition zones, and any other data that added to the knowledge of the orepass status.

3.1.1 Video and scan inspections

The condition of each orepass can be reviewed from available videos (Figure 4) and scans (Figure 5), and the orepasses categorised. The drawback of this approach is that these results are time-dependent, as they show the status of the orepass when the inspection was performed. During video inspections, additional information can be gathered, such as the modes of failure observed at current levels where the material is dumped into the orepass. The failures can be grouped based on the already existing damage mapping techniques. Primary failure modes include width increases, grooves in the floor of the orepass, fallouts on the intermediate level, height increases, increases in width and height, fallouts in the chute, and wedge failures in the orepass (Sjöberg et al. 2003).

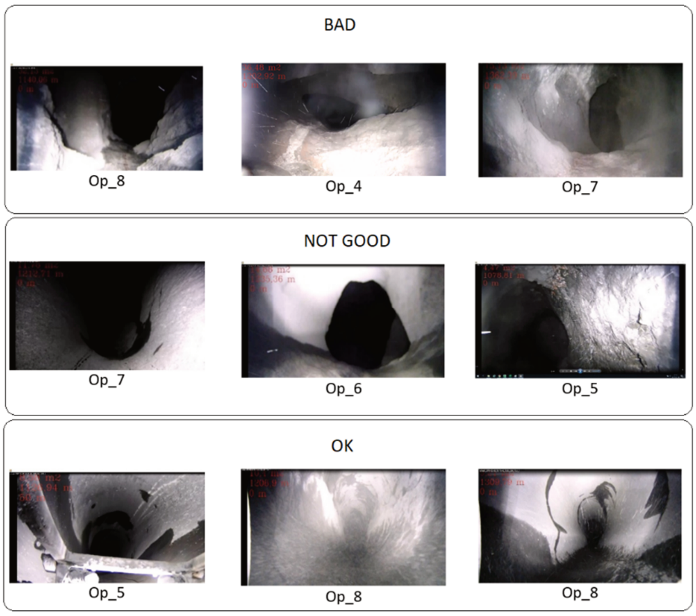


Figure 4 Orepass video inspection

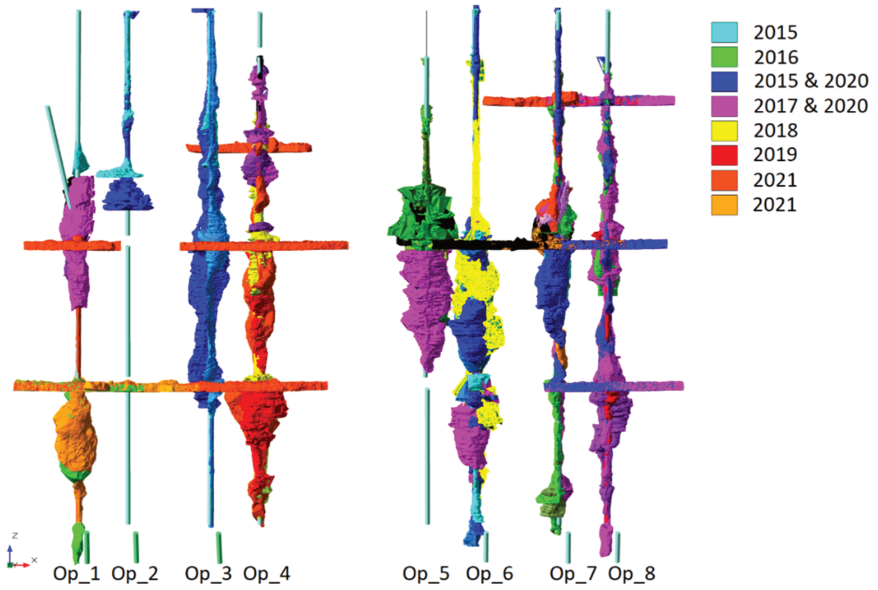


Figure 5 Orepass scans – 2015–2021

3.1.2 Stress regime

Numerical models are often the recommended method for assessing stress regimes. The tunnel condition index (Table 1) was used to approximate the stress regime; the status of the orepasses was observed by studying the scans, videos, numerical models, orepass renovation, and orepass history. With this information, the existing orepass wall stress regime could be estimated.

Table 1 Tunnel condition index (Brummer 1998)

Tunnel condition index	Status of the orepass	σ_1/σ_c
1	No cracks	<0.3
2	Small fractures	0.3–0.4
4	Extensive fractures	0.4–0.5
8	Walls cracked with rock fallouts and cavities	0.5–0.75

3.1.3 Geotechnical conditions

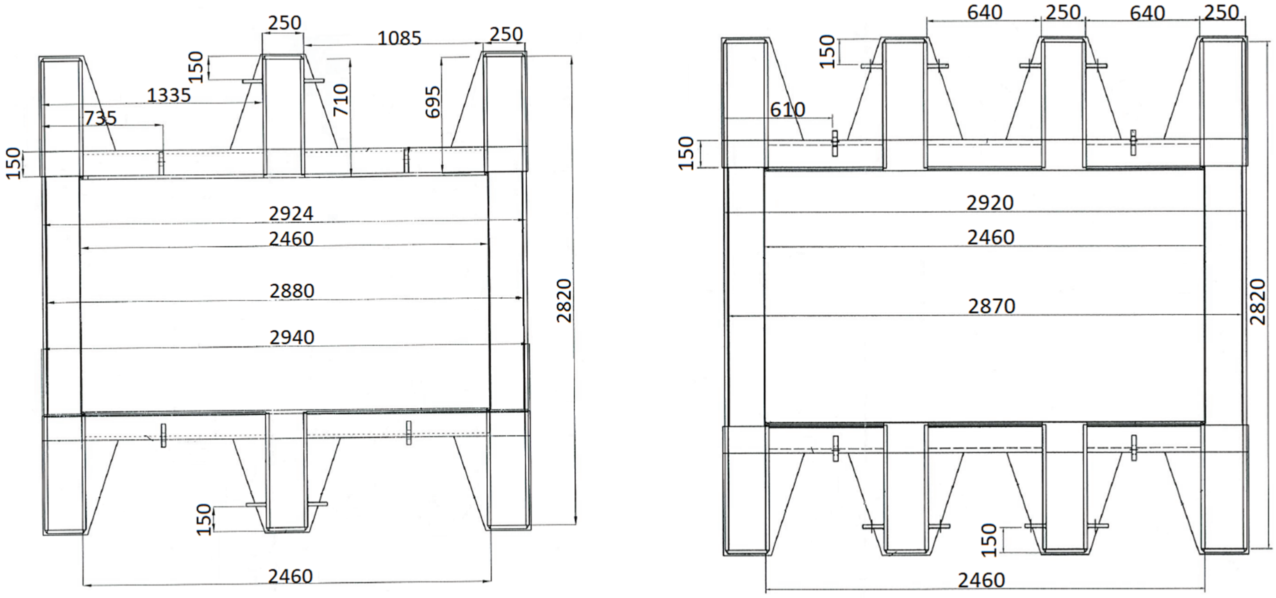
The geotechnical condition was based on the information obtained from LeapFrog models and internal reports, such as rock mass rating (RMR) values, joint sets, major structures, and lithology. The categorisation of geotechnical information was based on the modifying reduction factors shown in Table 2 for various RMR values.

Table 2 Rock quality

Modifying reduction factor	Rock mass rating	Quality
1.0	80–100	Very good
0.6	60–80	Good
0.5	40–60	Quite good
0.4	30–40	Bad
0.05	<30	Very bad

3.1.4 *Material size*

In Kiirunavaara Mine, the screening infrastructure comprises no screening, screening with one rail, and screening with two rails (Figure 6).



(a) (b)

Figure 6 Screening infrastructure used in Kiirunavaara. (a) One rail; (b) Double rail. All dimensions are in millimetres

To reduce the potential for the formation of hang-ups, Hambley (1987) suggested that the size of the largest block should be at least three times smaller than the diameter of the orepasses. The maximum size of rock fragments passing through the screening has been taken based on the maximum diameter of the rock fragments falling into the orepass (Table 3).

Table 3 Maximum rock fragment size passing through the screening

Scalper	Maximum rock fragment size	Orepass dimension	Best ratio	Worst ratio
No rail	1,400 × 2,460 mm	3 m	0.47	0.82
One rail	1,085 × 1,400 mm	3 m	0.36	0.47
Double rails	640 × 1,400 mm	3 m	0.21	0.47

The results show that the screening infrastructure used in the mine was only able to fall below 0.33 ratio (rock size/orepass diameter = 1:3) when the double rail was used and that only occurred in the best case scenario.

3.1.5 *Number of fingers/knuckles*

The degradation of the orepass walls can also be caused by the presence of finger raises and knuckles (Figure 7). Finger raises connect the main structure of the orepass with the production area levels, whereas knuckles are used to redirect the material and, in some cases, to reduce the impact of the material falling long distances. According to Hadjigeorgiou and Mercier-Langevin (2008), the presence of fingers and knuckles results in impact damage on the walls, but only in the particular place where the finger raise or knuckle is located. Kiirunavaara Mine develops one finger raise for each production level, and there are no knuckles in the orepasses.

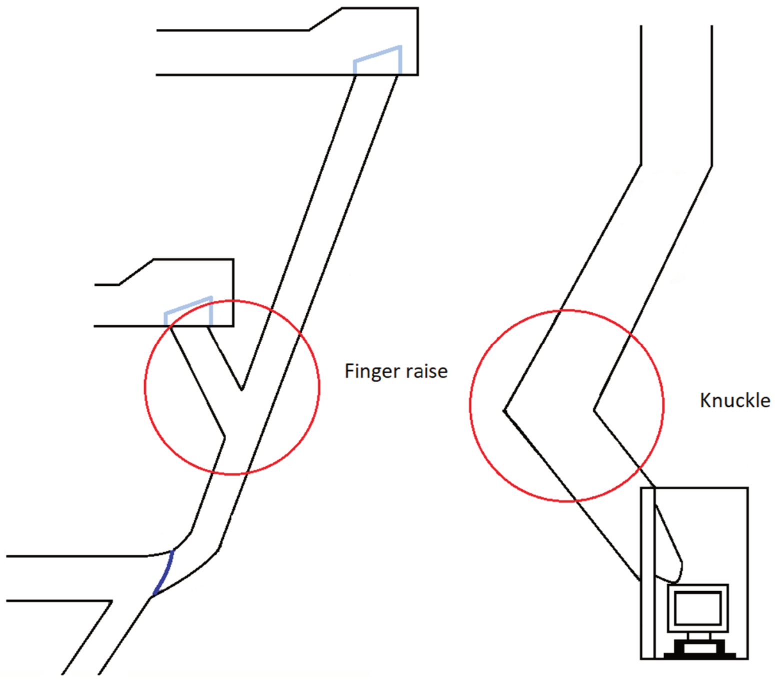


Figure 7 Finger and knuckle

3.1.6 Blasting hang-ups

The frequency and effectiveness of the blasting to restore the flow of material in the orepass depend on the accuracy of locating the hang-ups and the amount of explosives required to release them. At times, multiple blasts are required, as after one hang-up is released, a new hang-up can be formed, clogging the pass. Blasting the orepasses affects the orepass walls and speeds up the deterioration of the orepass; thus, blasting reduces the orepass longevity. Data from 2013–2021 were analysed to determine the frequency of the blasts per given orepass. In most cases, blasting to restore the flow of the orepasses occurred less than once per week; however, in some orepasses, the blasting was more frequent – from once a day to once a week. Today, loading practices have been adjusted, resulting in almost no hang-ups and much less frequent blasting.

3.1.7 Filling orepass

Orepasses can be operated in a flow-through, filled (kept near full), or near-empty manner (Skawina et al. 2022). Running the orepass in a filled manner improves its stability and prevents its expansion, but it also increases the risk of the formation of mud rushes (Lessard & Hadjigeorgiou 2003). Running the orepass empty can cause structural damage due to high impact, but this method results in fewer hang-ups, as it reduces the risk of the blocks arching over the chute throat and leads to less blasting (Skawina et al. 2022).

3.1.8 Extension factors: wall support

The use of ground support in orepasses has two functions: first, to provide stability during excavation, and second, to mitigate or prevent the effects of damage to the wall during the operation (Hadjigeorgiou et al. 2004; Hadjigeorgiou & Mercier-Langevin 2008). Rigid rockbolts do not work because the impact of the material flowing through the orepass causes the bolt to vibrate, destroying the bonding of the bolt (Stacey & Swart 1997; Hadjigeorgiou & Mercier-Langevin 2008). Resin grouted cables are more useful because they are less susceptible to vibration from rock impact as the rock travels through the orepass (Hadjigeorgiou & Mercier-Langevin 2008). Liners are beneficial to the structural stability of orepasses since they can protect installed reinforcement, and it is also possible to use some types of liners that provide resistance to impact and abrasion (Hadjigeorgiou & Mercier-Langevin 2008). Kiirunavaara Mine does not currently use any wall support in their orepasses.

3.1.9 Throughput and renovation times

An additional factor impacting the calibration of the longevity chart was related to the total throughput of the orepasses and renovation time stamps. The throughput and renovation stamps are shown in Figure 8.

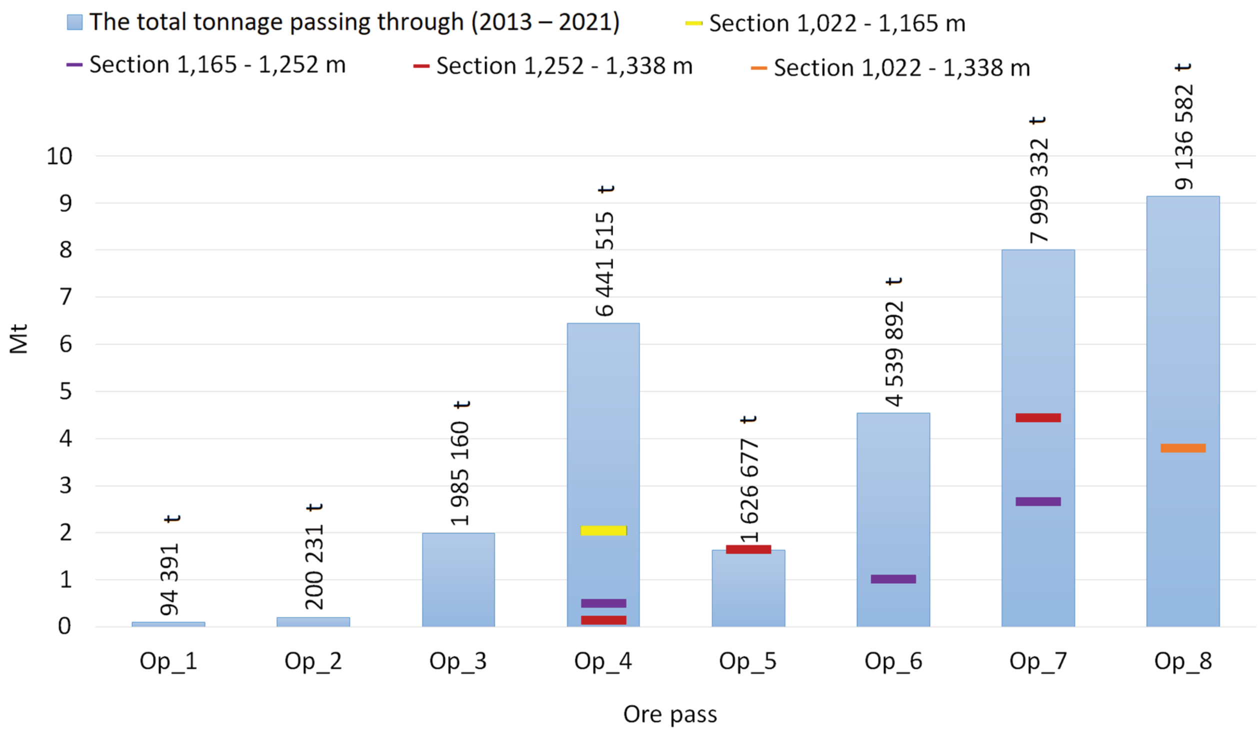


Figure 8 Throughput and renovation times of the orepasses

The blue bar shows the total tonnage passing through each of the orepasses from January 2013 until January 2021. The coloured horizontal lines show the renovation of the sections (if any occurred). Op_1 to Op_3 were affected by a seismic event and were not renovated. For Op_4 and Op_8, the entire orepass was renovated (from 1,022 to 1,338 m). For the former, renovation was done in three stages, and for the latter, the entire shaft was renovated in one step. The last section of Op_5, 1,252 to 1,338 m, was renovated, and Op_6 was renovated in sections 1,165 to 1,252 m. For Op_7, renovation took place in two sections, from 1,165 to 1,338 m.

4 Kiirunavaara's longevity chart

This study evaluated the longevity of the orepasses, taking into account the orepass longevity function and other adjustment factors. All parameters were collected for each orepass and the longevity chart was calculated for each orepass separately. Examples are shown in Figures 9 and 10. Op_1, for which the example is shown on Figure 9, was not renovated, therefore the first renovation is counted from the beginning of its life. For orepasses in which a renovation has taken place, the calculated value of the next renovation has been added to the previous one, as exemplified by Op_8 (Figure 10).

Parameter		Value (modify after Hadjigeorgiou & Mercier-Langevin (2008))
Adjustment factor	-	20
Stress Regime	medium stress	0.7
RMR – Walls	fairly good	0.5
Major Structure	no major structure	1
Orientation	good orientation	1
Material Size	one rail	0.7
Fingers/Knuckles	one finger per each production level	0.9
Blasting to restore	occasional blasting	1
Cushion guidelines	operated empty	0.5
Support	no support	1
Liner	no liner	1
	Estimated life span (Longevity function)	2.2 Mt
	Pushed through	0.09 Mt
	Life of the ore pass	20 Mt

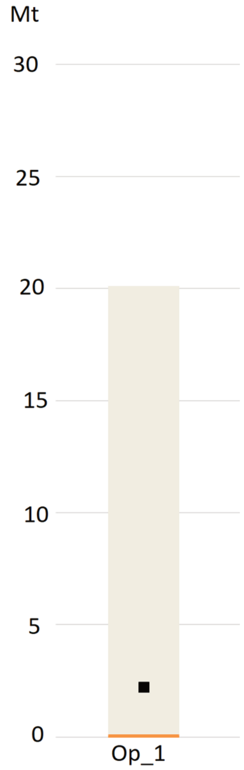


Figure 9 Longevity function calculation for Op_1

Parameter		Value (modify after Hadjigeorgiou & Mercier-Langevin (2008))
Adjustment factor	-	20
Stress Regime	medium stress	0.8
RMR – Walls	fairly good	0.5
Major Structure	no major structure	1
Orientation	fairly good orientation	0.8
Material Size	no rails	0.6
Fingers/Knuckles	one finger per each production level	0.9
Blasting to restore	less than once a week	0.9
Cushion guidelines	operated empty	0.5
Support	no support	1
Liner	no liner	1
	Estimated life span (Longevity function)	1.6 Mt
	Previous renovation	3.8 Mt
	Estimated next failure	5.3 Mt
	Pushed through	9.1 Mt
	Life of the ore pass	25.2 Mt

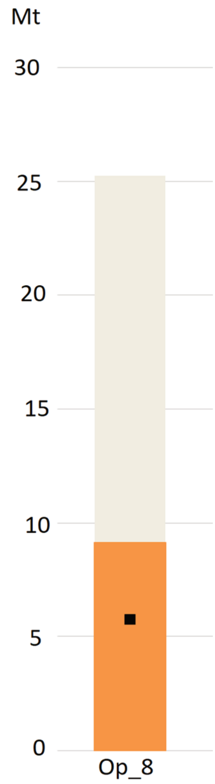


Figure 10 Longevity function calculation for Op_8

The correlated orepass longevity chart (Figure 11) shows the remaining material scheduled to pass through the orepass (grey colour), material that has already passed through the orepass (orange colour), and the first estimates of the next renovation time stamp for the orepass (black squares). In this study, the longevity chart represents the longevity index, taking into consideration sections and the whole length of the orepass. The space between the black square and the orange colour shows how much of the material will still pass through before the orepass needs to be scheduled for renovation. When the black square coincides with the orange colour, the orepass should be scheduled for renovation. Even if the black square goes into the orange bar and passes its planned renovation date, this does not necessarily mean that the orepass cannot be operated but doing so requires careful consideration.

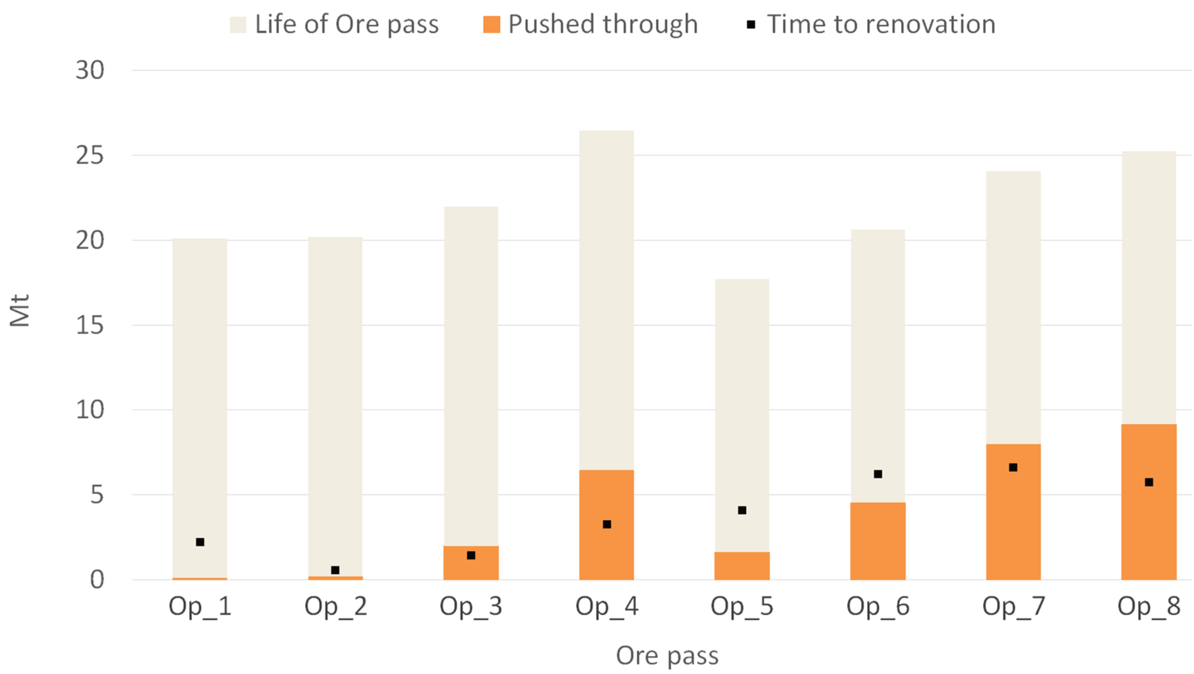


Figure 11 Orepass longevity graph with renovation time

As orepasses are divided into sections, in some cases, it is not necessary to rehabilitate the whole orepass, only its individual sections. Furthermore, due to the ongoing production, the upper sections of the orepasses will be out of use in later stages of the operations and thus do not necessarily have to be taken into consideration. They can be filled with concrete and abandoned. Based on the results, Op_1, Op_2, Op_5, and Op_6 still have time before they need renovation. The results obtained for Op_3, Op_4, Op_7, and Op_8 suggest the time of their renovation is approaching; this finding is in line with the current orepass renovation plan.

Discrepancies between the calculations and the real situation can be influenced by many factors, such as inappropriate estimation of missing parameters, incorrect use of shafts, unexpected events in the mine, or misinterpretation of the results. Depending on the amount of information the planner uses to select the index, the deviations can become larger.

Based on the results, the next renovations were scheduled, and the planning was updated with a renovation plan and a short-term production plan. The renovation plan is specific to orepasses, whereas the short-term plan is related to operational plans. This means that the longevity chart provides information about the future availability of the orepasses and acts as a partial input to a short-term plan.

5 Renovation plan

Taking into account longevity, estimated life spans, and total tonnes to be pushed through the orepasses, the renovation plan was updated. Based on the obtained results, the number of required renovations was calculated (Table 4). Orepasses that need to be renovated 10 or more times are considered critical. Special attention was paid to Op_1, Op_2, and Op_3, as they are located in the critical zone. Most of the studied orepasses reached the next estimated renovation time (2021), and two have already been renovated (the end of 2021 and the beginning of 2022).

Table 4 Renovations

Orepass	Life-of-mine plan (Mtonnes)	Time to renovation (Mtonnes)	Renovations (life-of-mine plan)
Op_1	20	2	10
Op_2	20	1	20
Op_3	22	2	11
Op_4	26	6	4
Op_5	17	4	4
Op_6	21	7	3
Op_7	24	8	3
Op_8	25	6	4
Summary			59

6 Conclusion

In this study, it was concluded that:

- Orepass longevity chart and renovation plans were implemented in Kiirunavaara Mine's planning schedule to more accurately prioritise future rehabilitation and maintenance of orepasses.
- Orepasses Op_1 to Op_3 were considered critical, as the estimated number of renovations is high, and renovating the orepass can take a couple to several months depending on the size of the enlargements and the length of the section renovated.
- Most studied orepasses have reached the next estimated renovation time (2021).
- Since the orepasses are divided into sections, it is not always necessary to renovate the entire shaft.
- Decisions on the necessity for renovation work are related to the ongoing production schedule, e.g. upper sections will be out of use in later stages of the operations.
- Scans, video inspections, and drilling data are important time-dependent information that should be collected throughout the life of the orepass.

Thus, the longevity chart, together with the short-term and long-term plans, should be continuously updated, as new information becomes available.

References

Berglund, J & Andersson, UB 2013, *Kinematic Analysis of Geological Structures in Block 34*, Kiirunavaara, Luossavaara Kiirunavaara AB (LKAB) Investigation, LKAB, Kiruna.

Beus, MJ, Pariseau, WG, Stewart, BM & Iverson, SR 2001, 'Design of ore passes, in underground mining methods', in Hustrulid, WA & Bullock, RL (ed.), *Mining Underground Methods*, Society for Mining, Metallurgy & Exploration, Englewood, pp. 627–634.

Brummer, RK 1998, *Design of Orepasses: Methods for Determining the Useful Life of Ore-passes Based on Previous Experience and Case Studies*, report to CAMIRO Mining Division.

Hadjigeorgiou, J, Lessard, JF & Mercier-Langevin, F 2004, 'Issues in selection and design of ore pass support', in E Villaescusa & Y Potvin (ed.), *Proceedings of the Fifth International Symposium on Ground Support in Mining and Underground Construction*, A.A. Balkema, Rotterdam, pp. 491–497.

Hadjigeorgiou, J & Mercier-Langevin, F 2008, 'Estimating ore pass longevity in hard rock mines', *Proceedings of the 42nd U.S. Rock Mechanics Symposium*, American Rock Mechanics Association, Alexandria.

Hadjigeorgiou, J & Lessard, JF 2010, 'Strategies for restoring material flow in ore and waste pass systems', *International Journal of Mining, Reclamation and Environment*, vol. 24, no. 3, pp. 267–282.

Hambley, DF 1987, 'Design of ore pass systems for underground mines', *CIM Bulletin*, vol. 897, pp. 25–30.

Lessard, JF & Hadjigeorgiou, J 2003, 'Ore pass systems in Quebec underground mines', *Proceedings of the 12th International Symposium on Mine Planning and Equipment Selection—MPES*.

Sjöberg, J, Lundman, P, Nordlund, E & Quinteiro, C 2003, 'Stability analysis of ore passes in the Kiirunavaara Mine', *International Society for Rock Mechanics 10th Congress*, The South African Institute of Mining and Metallurgy, Johannesburg, South Africa, pp. 1093–1098.

Skawina, B, Greberg, J, Salama, A & Gustafson, A 2018, 'The effects of orepass loss on loading, hauling, and dumping operations and production rates in a sublevel caving mine', *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 118, no. 4, pp. 409-418.

Skawina, B, Salama, A, Gunillasson, J, Strömsten, M & Wettainen, T 2022, 'Comparison of productivity when running filled, near-empty, or flow-through orepass using discrete event simulation', *Mining*, vol. 2, no. 2, pp. 186–196, https://doi.org/10.3390/mining2020011

Stacey, TR & Swart, AH 1997, *Investigation into Drawpoints, Tips, Orepasses and Chutes*, report to the Safety in Mines Research Advisory Committee, Project OTH 303, Mine Health and Safety Council, Johannesburg, South Africa, vol. 1.

Vatcher, J, McKinnon, SD & Sjöberg, J 2016, 'Developing 3-D mine-scale geomechanical models in complex geological environments, as applied to the Kiirunavaara Mine', *Engineering Geology*, vol. 203, pp. 140–150.