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THE RENAISSANCE OF UNDERGROUND RAIL HAULAGE – WHY UPCOMING MINING PROJECTS FOCUS ON THIS HIDDEN CHAMPION

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Abstract

In the past twenty years, substantial efforts have been made to introduce improvements to rail haulage systems and to catch up with the advantages of the other methods of haulage and conveyance in underground hard rock mining operations. Modern high performance rail haulage systems eliminate the historical disadvantages and have been able progressively to take over the 'number-one' position with regards to productivity, reliability, servicing and maintenance, impressively proven in some of the biggest underground mining operations like LKAB's Kiruna Mine and Codelco's Chilean copper operations. Together with the global trend of going underground using bulk mining methods within hard rock mining this leads to an increasing usage of rail haulage systems.

With regard to the choice of the most suitable haulage system it is necessary to analyze the advantages and disadvantages dependent on defined background conditions as well as to assess their economic influences and their 'weighting' within the overall context of mining operations. Therefore, an evaluation tool has been developed to identify the cost drivers of the various haulage systems through which especially the advantages but also the reduction of possible disadvantages of rail haulage for underground mining operation can be made transparent.

Zusammenfassung

Im Bereich der Zugfördersysteme hat in den vergangenen zwanzig Jahren eine starke Aufholjagt begonnen. Mit den heute eingesetzten Systemen konnten die Nachteile der Vergangenheit nicht nur eliminiert, sondern gegenüber allen anderen Fördersystemen gerade in Punkto Produktivität und Wartung die Spitzenposition eingenommen werden. Gemeinsam mit dem anhaltenden Trend zum untertägigen Hartgesteinsbergbau führt dies dazu, dass sich Züge als Fördersystem mehr und mehr durchsetzen. In Hinblick auf die Auswahl des geeigneten Fördersystems gilt es, die je nach Einsatzfall unterschiedlichen Vor- und Nachteile zu analysieren und deren wirtschaftlichen Einfluss auf das gesamte Abbausystem zu bewerten. Hierzu wurde ein Modell zur Identifikation relevanter Kostentreiber entwickelt, durch welches gerade die Vorteile und auch die Möglichkeiten zur Reduzierung potenzieller Nachteile von Zugfördersystemen transparent gemacht werden können.

Haulage systems for underground hard rock mining

The ongoing development of large scale bulk mining activities in underground hard rock mining brings the loading and haulage systems into question which require improvement, as these frequently represent the bottlenecks in the mining process. Innovative problem solutions attempt to address the need for a synchronization of the mining process chain: Extraction, loading and haulage of ore. It is especially the haulage which occupies a major role. Current techniques are continually being reviewed because these take up between 15 and 30 percent of the overall capital investment in a mine and an ever more significant part of the production costs [1].

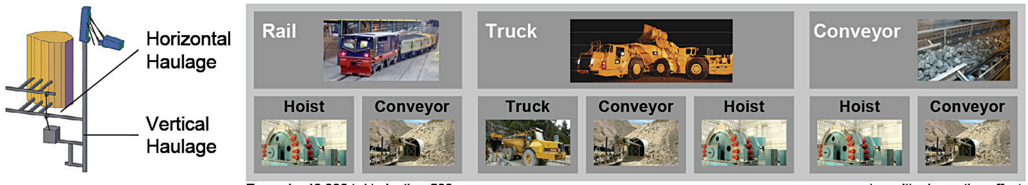
In recent decades, the increase in production by bulk mining methods has led to more and more progress in extraction techniques which also in turn has led to significant advances in materials handling. Whilst, during the seventies, ore haulage was almost always carried out with rail haulage systems, the method has as a result of technological progress been practically superseded. Progress in decline access has enabled the use of alternative systems of haulage, such as underground haul trucks and conveyor belts.

The use of haul trucks has meant that the risk in the absence of parallel backup for and the susceptibility to disruption of rail haulage systems have been reduced. Even the cost of servicing and maintenance of an electrically driven DC locomotive has not proved any great advantage over the use of diesel engine driven haul trucks. In addition, production processes with haul trucks have an advantage over the service life of mining operations because of the ease in which operations can be scaled up or down. It is much easier to react more flexibly to ever changing background conditions by adding or removing trucks. Energy and environmental conservation aspects have however been neglected.

Conveyor belts have also been able to gain more market share with the development of stronger and more cut resistant belt coatings, but the conveyor has the same issues of flexibility as rail haulage. In coal mining, however, this has been different. The increasing reliability and the advantage of continuous transportation away from the face has led to the situation where trains have practically been superseded everywhere by conveyor belts for the extraction of coal.

Nevertheless, the use of trains for underground haulage systems has not been entirely superseded – especially in the North- and South Americas as well as in South Africa, where rail track systems and trains remain a seriously considered alternative. With the technological development of rail haulage systems in recent years (high degrees of automation in conjunction with modern electrical AC-drives), haulage with trains has again gained significance, not only from the technological point of view but also from the business and economic aspects [2].

Within the scope of underground hard rock mining, a number of common haulage systems are being employed (see the illustration in fig. 1). With increasing focus on long-hole open stopping, sub-level caving and block caving, where large volumes of mined material are to be moved, haulage can be divided into two segments: horizontal haulage from the underground draw point level, and the vertical haulage from the underground collection/ deposit site to the surface processing plant and equipment above ground.



Example: 40.000 to/d, depth > 500m — +/- positive/ negative effect

	Rail: Hoist	Rail: Conveyor	Truck: Truck	Truck: Conveyor	Truck: Hoist	Conveyor: Hoist	Conveyor: Conveyor
Capex over mine life time							
Infrastructure							
Tracks/ Roads	o	-	-	-	o	o	-
Mine Automation	-	-	o	o	+	o	-
Tunnels/ Shaft (length)	+	o	-	o	+	+	o
Ventilation (heat emission)	+	o	-	-	o	o	-
Ventilation (pollution)	+	+	-	o	o	+	+
...	-	-	o	+	+	o	-
Capex over mine life time							
Equipment							
Crusher	o	o	+	o	o	-	-
Horizontal Haulage Devices	o	o	-	-	-	o	o
Vertikal Transportation Devices	o	-	-	-	o	o	-
...							
Planning	-	-	+	o	o	-	-
Operating Cost							
Labour Cost (Operations)	+	+	-	o	o	+	+
Maintenance							
Equipment (horizontal, e.g. wheels)	+	+	o	o	o	-	-
Equipment (vertical, e.g. hoists)	o	-	o	-	o	o	-
Infrastructure	o	o	-	o	o	+	+
Energy	+	+	-	o	o	+	+
Safety	+	+	-	-	-	+	+

Figure 1: Qualitative evaluation of possible haulage combinations

Horizontal haulage is carried out using one or two of three haulage systems: In bulk mining applications such as block cave mines the ore on the extraction level is passed to the haulage level through vertical ore passes. The ore is moved from the draw point to the ore passes using a 'load-haul-dump' machine (LHD). Loading is undertaken at the bottom of the ore pass onto trains, haul trucks or conveyor belts. In the case of truck haulage application, there is also the alternative of a combined extraction and haulage level with a single-step LHD to truck haulage chain. This is common with sub-level caving systems. The haulage is then undertaken to a transfer station for the vertical haulage, i.e. from underground to surface out of the mining area.

For vertical haulage purposes, there are also three different methods available: Haulage by haul trucks through a 'decline' roadway, haulage via conveyor belts and haulage via haulage shafts. Unfortunately, such methods cannot be easily combined with the previously described horizontal haulage systems.

In the case of horizontal rail haulage systems, the vertical haulage can, after transitional unloading/ reloading, be undertaken through haulage shafts or by conveyor belts in a declined shaft, at a gradient smaller than 1:3. Both systems require primary crushing of the ore before loading. As the ore has to be crushed for the horizontal haulage with conveyor belts at the ore pass loading point between the extraction and the haulage level, both processes are applicable. Haul trucks are commonly used to haul ore from the production face to the surface but depth and haulage volume are constraining factors which raise the cost.

On the one hand, the underlying morphology should serve for a relative comparison of a variety of combinations of horizontal and vertical haulage (see next chapter). On the other hand, it should serve as a basis for an economic and performance modelling of different haulage scenarios (see subsequent chapter). The results of such a model thus represent the cost drivers of the various haulage systems and their influence on the overall mining operations. Moreover, they provide trend statements on the advantages of certain haulage systems dependent of pre-defined background conditions, such as for example the targeted daily production, the characteristics and the position of the ore body, and the anticipated life of the mine. The last two chapters then investigate and present more closely the advantages and the reduction of the potential disadvantages of a rail haulage system in particular.

Advantages and disadvantages of existing haulage systems

The underground haulage systems described in the first chapter indicate a variety of advantages and disadvantages upon closer examination, dependent on the particular application in question (see Fig. 1). This has also an influence on the various suitabilities in specific cases of application. The aim of this chapter is therefore to give a qualitative comparison of the variety of haulage systems. On this basis, the evaluation tools described in the next chapter can provide an indication of the economic influence of the advantages and disadvantages and their 'weighting' within the overall context of mining operations.

Rail haulage

In the past twenty years, significant efforts have been made to introduce improvements to catch up on the advantages of the other methods of haulage and conveyance. The current available systems eliminate the previous disadvantages (among other things, low reliability and a high degree of expenditure on servicing and maintenance of electrical DC-technology), and have been able progressively to take over the 'number-one' position in regard of productivity, servicing and maintenance [2]. The state-of-the-art AC-electrical technology based systems (see fig. 2) have demonstrated extremely low expenditures on servicing and maintenance routines, which in combination with a long service life is particularly advantageous for mine working operations with a long-term business horizon [3]. In addition, the train haulage systems take greater consideration of safety and ecological environment regulations for example with zero emissions, fully automated driverless operation and low operating energy consumption [3]. On the other hand, this is offset by the high initial capital investment costs (Capex) which poses an important expenditure position.

With vertical haulage being limited to either a hoisting system or a declined shaft system with conveyor belts, the advantages of a horizontal rail haulage system become apparent particularly for large daily production volumes. Economies of scale start taking effect with a large basic volume of material to be hauled. Technologically speaking, the principal disadvantages of the rail haulage systems are their interrupted/ intermittent operation and the limited gradability. The other common complaint, that rail haulage systems are inflexible, can now be largely discounted (see last two chapters). The technological advantages are the fact, that run-of-mine material can be transported without difficulty, curves in the system are possible and above all, large distances can be covered quickly and with very few staff requirements.

Figure 2: Example of SCHALKE's full automated rail haulage system at LKAB

Truck haulage

In truck haulage systems, a general differentiation can be made between diesel engined and electric powered haul trucks. The electric powered haul trucks have not yet become adopted in many mines [4]. The reason for this is that they are expensive compared to a diesel truck, require catenary, concrete roads, have medium capacity only (30 - 50 tons) [5] as well as the fact, that in spite of a higher potential degree of automation, drivers are still required. Therefore, greater focus is thus placed on the established diesel engined haulage system.

The operational availability of diesel engined truck haulage systems is maximum 85% due to maintenance requirements and the fact that they have a driver. Utilization does not often exceed 65% because of the dynamics of the truck haulage system with waiting time for loading, passing and the fact that the drivers are human. In contrast to the previously described rail haulage system, diesel engined haul truck systems can be easily scaled depending on the production volume and thus prove advantageous for employment under conditions of very small to medium daily extraction volumes. Such a system is recommended thus mainly for mines with short time periods of useful life, and not least because the useful service life of a haul truck is around 30,000 operating hours. The advantage of truck fleet flexibility has also disadvantages in cases of increasing volumes, because the more haul trucks required, the greater the expenditure on logistics and coordination. There are also inherent target conflicts in the form of workplace safety and ecological environment conservation. With greater number of haul trucks used the expenditure on workplace safety rises more than proportionally.

Because of the large workforce requirement, haulage by truck has disadvantages in comparison with rail haulage and conveyor belt systems. The consumption of fossil fuels and the associated emissions counteract recent efforts and success in underground health and safety – besides that they do not only harbor difficulties with the ecological environment and sustainable development but also have economical drawbacks. The long-term aspects of oil-price increases and high expenditures on underground ventilation lead to higher production costs, quite apart from the increased labor costs – while future mining operations take place in more and more isolated fly-in-and-out areas. From a technological perspective, however, diesel engined haul trucks offer a maximum in flexibility.

Apart from exploitation over a time scale of varying loading and unloading stations, underground inclines of 15% can be handled and curves can be built into the underground roadways. Beyond such, however, considering horizontal haulage, combining extraction and haulage levels is possible where haul trucks can be directly loaded within 'LHD' systems. Analogous to rail haulage, there are no real restrictions as regards the broken size of the ore-bearing hard rock material, so that even in cases of vertical haulage with trucks, no transition stations or crushers need to be installed below the surface. Nevertheless one disadvantage is the fact that diesel fuel needs to be taken and stored underground. In cases of deeper pits, the Capex advantage of 'declines' turns into a disadvantage in comparison with vertical shafts.

Conveyer-belt haulage

Haulage by conveyor belt places clear demands upon the type and broken size of the extracted ore-bearing hard rock material being hauled. As a rule, the ore from the draw point is generally too coarse for conveyance by conveyor belt and needs to be crushed to approximately -100mm prior to loading. Crushing equipment is therefore set up at the bottom of the ore pass at each loading station. The resulting high requirement for crushers therefore leads to a significant disadvantage in comparison with rail and truck haulage systems where only a few large crushers are needed at the central unloading stations.

Independent thereof, the abrasive nature of the ore material has to be taken into the economic calculation. Even if the construction components and the material characteristics of new conveyor belts have essentially been improved, the ongoing reduction of wear-and-tear through abrasion represents a continuous challenge on the engineering. When no crushing equipment is available at the head of the conveyor run, the great variety of size of the hard rock material over the extraction time leads to additional difficulties in the extraction/ transportation cycle.

The great advantage of conveyor belt systems is, however, to be seen in the possibility of the great volume of material it can move. In this regard, the high capital investment costs for the system as well as the not to be underestimated expenditure on control, servicing and maintenance routines can be spread over the volume of tons conveyed in an ever reducing cost/ performance ratio. But this advantage also represents a disadvantage in mine workings with usually relative low daily production volumes.

As far as the aspect of current ecological environment conservation regulations is concerned, conveyor belts systems are equally as viable as rail haulage systems: zero emissions coupled with electrical energy efficiency. The only emission to be counted in the calculation is the heat emission. As far as labor safety is concerned, the positive effect of unattended/ unmanned operations is countered by the fire hazard emanating from the many continuously running electrical motor drives and rollers required in a conveyor belt system.

From the technological aspect, haulage by a conveyor belt system is currently the only established continuously running process, and thus ideally supplements efforts for introducing continuously working extraction routines. The possibility of negotiating inclines of up to 20% makes a belt conveyor system approach the advantages provided by truck haulage, for achieving horizontal haulage and vertical conveyance, without the necessity of underground transitional loading and unloading stations. This advantage, however, must be qualified by the restrictions imposed upon the path. Since no curves are possible, changes of direction have to be enabled by complex and elaborate transition stations. Such a system is extremely inflexible. For this reason, the benefit of the system reduces in cases of large mining operations, and not least because of the inherently increasing complexity and breakdown hazard without a parallel backup system.

Hoisting

Vertical shaft hoisting is common in both vertical plane and steeply dipping (>1:3) horizontal plane operations. The method always requires a primary crushing and loading station at the shaft bottom and a bunker as buffer storage. Accordingly, there are certain minimum requirements placed upon the selected overall system (e.g. transitional unloading and loading stations with crusher equipment), which have been previously described above.

The main disadvantage of shafts is the high capital investment costs and relatively high maintenance costs. Only by means of a corresponding high haulage volume economies of scale can be achieved, and thus the conveyance costs per ton brought into a competitive zone. A direct comparison of vertical and sub-vertical shafts with conveyor belt systems depends on the relative depth of the mine. However, there still exists a certain economic limit of mine-depth, after which the break-even point for haulage through shafts is obtained. A similar comparison is also possible with haul trucks. Technologically, shafts are also an interrupted/ intermittent form of transportation system, which can be exploited in a variety of ways. Alongside the actual haulage of the ore, such shafts are also be used for safety functions, man riding, services and ventilation purposes.

In comparison there are multiple different haulage systems and technologies available, they all have their well-known pro’s and con’s and their common main application scenarios. But recent technology improvements initiated a new evaluation of these systems and the rules of thumb in mine haulage planning.

Against the background of the significant improvements in rail haulage technologies and the impressive demonstration of the performance, outstanding reliability and economics in some of the world’s largest underground high performance mine operations like LKAB’s Kiruna mine and Codelco’s Chilean copper operations show, that the benefits of today’s state-of-the-art underground rail haulage are back in competition and getting more and more into the focus of upcoming large mining projects.

Development of an evaluation tool

As mining conditions and therefore the haulage requirements and application scenarios differ from orebody to orebody and are depended on many influence factors, a Microsoft Excel™ based model has been developed to allow a comparison of the costs of haulage in a bulk underground mining environment. Bulk haulage for this exercise has been defined as a requirement to move more than 5,000 tons ore per day (1.7mtons ore per year).

An initial evaluation dentified options of horizontal and vertical haulage available to mine designers which build the necessary elements to be included in the model (see previous chapters).

It was also identified that the vertical component could include a horizontal or declined haulage portal from the side of a mountain requiring different solutions or a combined solution. One example is PT Freeport Indonesia's Grasberg mine in Irian Jaya where rail provides the initial haulage then conveyor carry the ore to the mill. As the majority of mines require a vertical or sub-vertical method of haulage the model makes no particular allowance for horizon or down dip access.

Mine design factors

In order to set the parameters for the model size, shape, depth and content of the orebody were included. A massive orebody with a length to width ratio of around 3:1 and a depth of +100 meters will lend itself to bulk mining. A long and thin orebody with an aspect ratio of 30:1 will lend itself to a less continuous method. An orebody 400± meters below the surface will have access options while an orebody of 600+ meters predefines an access by shaft.

There are many different mining methods but only a few lend themselves to bulk haulage systems. The following methods were included in the model as they represent the main bulk mining systems widely in use:

- Block cave operations are used in low aspect ratio orebodies where the geology is suitable with ore tonnages typically greater than 10 million tons per year. Typically, the orebody is vertical or only slightly sub-vertical and is rectangular or squared in shape;
- Sub-level caving is used with ore tonnages between 3 and 10 million tons per year having a deep orebody that is more rectangular but thick – a medium aspect ratio;
- Long-hole open stoping orebodies is applicable where the ore tonnages are typically less than 10 million tons with an orebody that has a high aspect ratio.

All such orebodies are able to be bulk mined and daily tonnages of 5,000 tons or greater are common. The movement of such large tonnages opens the opportunity of mine planners to consider options apart from the common truck haulage.

Horizontal haulage cost considerations

In building the model the main drivers of the decision on the type of horizontal haulage were considered. These include:

- Ventilation requirements;
- Access and development of the orebody in preparation for extraction;
- Capital cost (Capex);
- Operating cost (Opex); and
- Vertical haulage system to be used

The costs included in the model are derived from data received from actual mining costs and quoted costs for the work to be carried out by contractors.

Ventilation

One of the largest cost factors of an underground mine operation is ventilation. This is particularly the case – due to the lack of a power grid connection in most mining projects – where a large number of diesel-powered equipment is used to generate fan and air conditioning power. The statutory requirement around the world is that a mine requires 0.06 – 0.063 cubic meters per second of airflow for each kilowatt of power of underground diesel equipment.

Where a mine is running 10 haul trucks with 500kW engines the ventilation requirement is 31.5m^3/sec for each haul truck and 315m^3/sec for the fleet. This requires a dedicated air intake and fan with an output of greater than 300m^3/sec (one vent shaft) and over 1200kW of electric power to provide.

Ventilation for conveyor and rail haulage is considerably lower as they typically use electric or battery power. Hence, normal mine ventilation for the other mining activities is sufficient. In conveyor operations where the identified risk is frictional ignition the ventilation requirement may be greater than for a rail system.

When a diesel locomotive system is used the quantity and power of the engines will be significantly less than a haul truck fleet for a given tonnage hauled.

Access and development

Depending on the depth below the surface of the orebody and the mining method selected the type of access to the orebody has to be determined. This may be a shaft access or a 1:7 decline access from the surface, a decline from an existing open pit mine or an adit from the side of a large hill or mountain that provides direct access to the orebody. A decline or adit will use truck haulage for the primary excavation and the development of the undercut, production level and haulage level will be carried out using truck haulage as they have a flexibility and capability that cannot be surpassed in this application. In the development of a large bulk excavation mine the pre-mining work will take up to 5 years to complete. This equals the productive life of a truck (~ 30,000 hours).

If the decision is to continue using haul truck for production haulage, depending on the fleet size, it will require discrete ventilation. A shaft to provide sufficient ventilation for a large haul truck fleet will be at least 5.0 meter in diameter and will have to be excavated and fitted out as part of the mine development.

Specific excavation requirements are necessary if the mine is planned with rail or conveyor haulage. From the pre-feasibility stage the need for large amounts of additional excavation can be eliminated or significantly reduced. Conveying works best with long straight roadways and rail haulage with standard gauge requires curves with a radius of not less than 60 meters. A smaller radius can be used for narrower gauge tracks.

Capital cost (Capex)

The largest component of the Capex is the initial purchase of the equipment. The model focused exclusively on the Capex for haulage equipment purchase. LHD’s for production are not included as they are common to all systems.

Apart from purchase of the equipment the Capex also includes the infrastructure. In the case of rail this includes the track, loading and unloading systems, signaling and communication infrastructure. A conveyor system includes a loading and transfer system from belt to belt plus the drive, control and communications systems. A conveyor will also consist of an extensive monitoring system and fire suppression system.

With both the rail and conveyor haulage the capital spent will tend to be at the beginning of the project whereas a trucking system will have capital spread over the mine life.

Operating cost (Opex)

The ongoing operating costs of the three major horizontal haulage systems show a very large cost burden for trucking contrary to significantly lower Opex for conveying and rail systems. Rail haulage offers a very low cost of maintenance per ton hauled, with conveyor Opex at around 3 times the cost of rail and truck haulage over 6 times the Opex of rail per ton hauled.

Vertical haulage

The model includes vertical haulage because of the cross-over of truck and conveyor to vertical haulage. As for horizontal haulage the ventilation requirements for trucking seriously influence the costs of trucking for vertical haulage. The real estate requirements for conveyor haulage over vertical distances greater than 1,000 meters limit its use for this task.

Hoisting is by far the most prevalent method of haulage for bulk mining operations. Where the total tons hauled per year are less than 2.5 million tons and the vertical haul is less than 600 meters trucking is and will remain a preferred option.

Model outputs

The Excel tool includes the above mentioned characteristics, performance and cost figures. The uses is free to set up scenarios within each systems limitations and finally to calculate performance and cost figures. Despite the huge potential as supportive tool for mine planning projects, as a general outcome the model shows a number of interesting points:

- At a production rate of less than 8,000 tons per day the haul truck is the lowest cost alternative for horizontal haulage.
- The higher the production volume the more advantageous rail and conveyer haulage become – depending on mine-specific factors such as depth, material characteristics, profile and length of the tunnels.
- Rail equipment has a long life with limited requirement for additional equipment and less Opex after initial set up.
- Rail maintenance costs are the lowest of the three methods while the system itself provides the highest availability.
- Rail haulage has the lowest labor cost.

Besides the economical evaluation other factors such as health and safety, automation, sustainability and ecological impact may lead to the decision for rail haulage systems (and in special cases maybe also for conveyors) not only at high production volumes.

Higher flexibility and lower initial Capex because of Schalke's locomotive technologies

As already indicated in the model and mentioned in the prior chapters, in a lot of mining scenarios rail could be the best option for a suitable underground haulage solution. As established, the significant advantages of an underground rail haulage system are the very low operating costs and according to this the lowest TCO (Total Cost of Ownership over equipment lifetime) for multiple haulage scenarios. As described above, some of the biggest mining companies worldwide realized this great benefits and rely – against the background of many years of experience on KPI and cost figures – on Schalke's rail technology. More than that – recently they extend the rail haulage capacities.

This actual development – especially in a weak market environment as the mining sector is facing these days, where the initial Capex becomes more important than the TCO and short term effects are dominating long term benefits – is seen in many discussions as the starting point of a general paradigm shift back to rail haulage systems in underground bulk mining operations.

In general, for new mines or levels the mining companies try to minimize the initial Capex and preproduction cost and time; major goal is a fast production ramp-up to generate revenue as soon as possible. Because of this development it seems that the major advantages of rail haulage systems (lowest TCO) become less important. However, Schalke's new strategy minimizes the major disadvantages of rail haulage systems (i.e. high initial Capex) by using Schalke's "modular multi" system locomotive technologies. Through this technology production can be started earlier and the costs can be reduced as well. As a specialist for safe, reliable high-performance drive units, the German-based company Schalke provides a range of mining locomotives from 10 to 130 tons as well as service and/ or shunting locomotives.

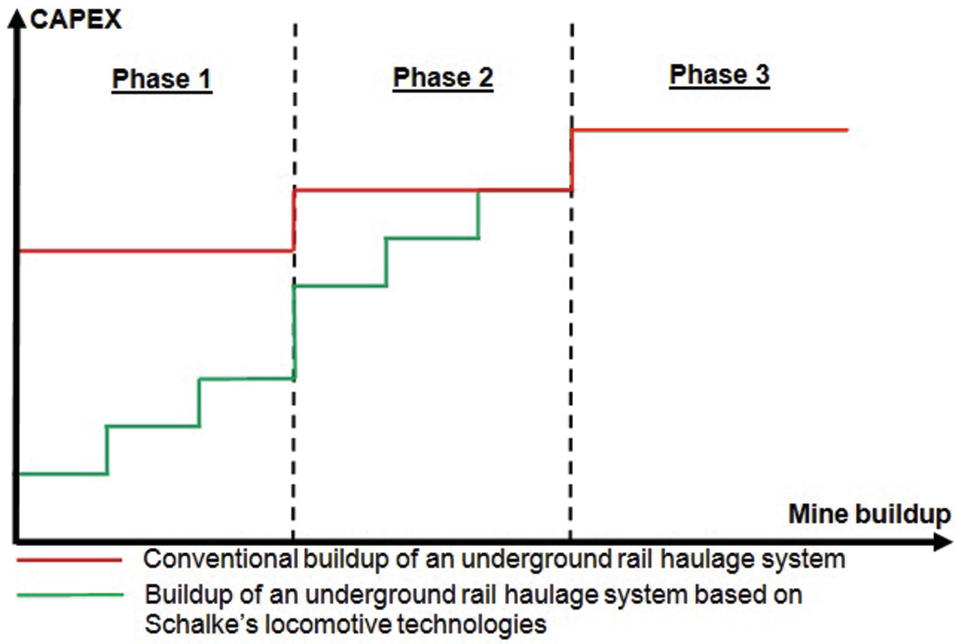


Figure 3: Reduction of Capex by using a new strategy based on Schalke's "modular multi" system locomotive technologies

Usually a conventional buildup of an underground rail haulage system is divided in a few phases, e.g. three phases as shown in our example in figure 3 (marked in black). Because of the high ventilation costs and increasing environmental issues electrical solutions will win over diesel operations in the near future. Hence, we have chosen an electrical solution for our example. In case of a conventional buildup (marked in red in figure 3 and shown in the upper area of figure 4) the investments for the phases in our example are:

- Phase 1 (first production):
  - complete "main rail infrastructure" (incl. catenary and low and medium voltage (LMV) system)
  - first train sets (trolley-locomotives) and first loading/ unloading station(-s)
- Phase 2 (enhanced production):
  - partial "extension rail infrastructure" (incl. catenary and LMV system)
  - additional train sets (trolley-locomotives)and additional loading/unloading station(-s)
- Phase 3 (final production):
  - complete "extension rail infrastructure" (incl. catenary and LMV system)
  - final train sets (trolley-locomotives) + final loading/unloading station(-s)

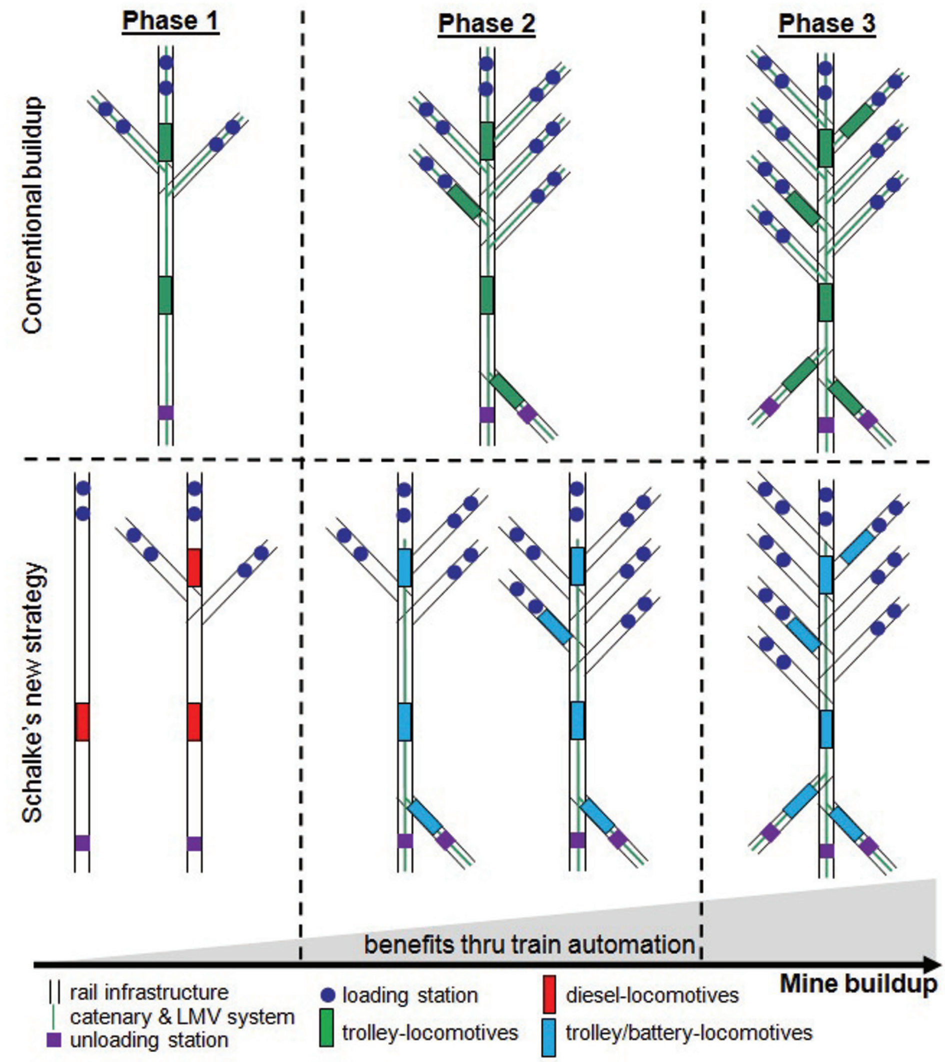


Figure 4: **Conventional buildup of an underground rail haulage system versus new strategy based on Schalke's locomotive technologies**

A Buildup of an underground rail haulage system based on Schalke's locomotive technologies (marked in green in figure 3 and shown in the lower area of figure 4) allows minimizing the initial Capex, to start production early and generate revenues. Each of the three phases can be divided in several intermediate phases:

- Phase 1 (fist production):
  - a. Initial first production

        - partial “main rail infrastructure” (no catenary and LMV system)
        - one first train set (diesel-locomotive)
        - first few loading stations and one unloading station
    - b. Increased first production
        - additional (or final; depending on the scheduled intermediate phases for phase 1) “main rail infrastructure” (no catenary and LMV system)
        - additional train set(-s) (diesel-locomotives)
        - additional loading stations
        - if necessary additional unloading station (depending on the scheduled production for phase 1)
    - + X additional intermediate phases (equal to intermediate phase b.) depending on planned total production for phase 1. The number of trains using diesel locomotives can be increased as long as the installed ventilation of the final production set-up can handle all the diesel exhausts.
- Phase 2 (enhanced production):
    - a. Initial enhanced production
        - first “extension rail infrastructure” (no catenary and LMV system)
        - upgrade of “main rail infrastructure” with catenary and LMV system
        - upgrade of the existing train sets to battery/trolley-locomotives
        - additional loading/unloading station(-s)
    - b. Increased enhanced production
        - additional “extension rail infrastructure” (no catenary and LMV system)
        - additional train set(-s) (trolley/battery-locomotives)
        - additional loading/unloading station(-s)
    - + X additional intermediate phases (equal to intermediate phase b.) depending on total planned production for phase 2.
- Phase 3 (final production):
    - complete “extension rail infrastructure” (no catenary and LMV system)
    - final train set(-s) + final loading/unloading station(-s)

The key of this game-changing strategy are Schalke’s modular multi system locomotives called “ModuTrac”:

- “Modular” means that the power supply system can by changed directly on one locomotive, e.g. from diesel to battery (and/or vice versa) via Schalke’s innovative power-pack system. Hence, only the power-packs have to be changed, not the complete locomotive. E.g. it is possible to start with a diesel power-pack and change later on to a battery power-pack. There is no need for Capex in a catenary system from day one.
- “Multi” stands for more than one installed power supply system on one locomotive (up to three realized by Schalke until today). The best example is the battery/trolley-

combination, with which it is possible to drive on the main lines using catenary power and on the extension lines using power from onboard batteries (no Capex in a catenary system on the extension lines, at no times).

- "Modular multi" is the combination of both above mentioned technologies. It is possible to start with a diesel power-pack and change later on to a battery power-pack with an integrated trolley system on the roof for catenary operations.

Figure 5: MMT-M-270-BDE – Schalke's "ModuTrac" mining locomotive running on battery or diesel power-pack with integrated trolley system

One example for this new strategy is shown by Schalke's MMT-M-270-BDE "ModuTrac" locomotive (see fig. 5). This locomotive will run in PT Freeport Indonesia's Grasberg mine, which is currently going underground. The locomotive is designed with a central cab, weight of 40 tons and is currently the heaviest twin-axle locomotive Schalke manufactures. Each wheel set is driven by a 135-kW AC electric traction motor. Two state-of-the-art, amongst others liquid-cooled IGBT-controlled traction converters make it possible to control each wheel set individually. The locomotive design is based on the "modular multi" system featuring a trolley system for overhead catenary operations and one traction power-pack, either battery or diesel. Changing from one power-pack to the other can be quickly and smoothly done in approximately one hour. This "ModuTrac" mining locomotives are equipped with several state-of-the-art traction technologies simultaneously and are perfectly matched to the above mentioned strategy.

Furthermore, the MMT-M-270-BDE “ModuTrac” locomotive features numerous characteristics typical for Schalke products that keep operating and maintenance costs low. These include the electro-dynamic main brake, which is powered by traction converters and strong enough to bring the entire train to standstill if required. In case of emergency or for prolonged parking, the locomotive is equipped with a pneumatic service brake, which includes a spring-loaded function. Moreover, a highly efficient slip-and-slide protection system is used, ensuring the optimal use of available tractive forces, depending, of course, on the wheel-rail friction coefficient. State-of-the-art AC traction technology ensures reduced maintenance costs and standstill period compared with DC traction systems.

With Schalke’s modular power-pack system technologies the locomotives are directly prepared for future technologies as well. Besides the change e.g. from diesel- to battery-power-packs during mine buildup, more precisely said plug-and-play and low priced upgrade of the locomotives, which avoids an immense investments in new locomotives, the power-packs themselves can be replaced/upgraded later on. For example today’s mostly used traction batteries, because of the best price/performance ratio, are lead-acid batteries. But in the near future this “older” technology will be overtaking by lithium-ion technologies. In this case Schalke’s locomotives with lead-acid battery-power-packs mustn’t be replaced completely; just the old power-packs must be replaced by new lithium-ion battery-power-packs without changes, adaptations or whatever on the locomotives per se. According to this same locomotives just equipped with new power-packs can e.g. drive much longer on battery power without recharging; and all that without immense investments in new locomotives, but rather favorable investments just in new power-packs. Same upgrade possibilities exist for diesel-, trolley- and multi-traction-power-packs, e.g. battery/trolley-power-packs, as well.

Lower operating costs because of a complete automated and integrated underground rail haulage system from one single source

As shown in figure 4 the benefits of train automation and integration in the whole system - starting from train protection (ATP) up to automatic train (driverless) operations (ATO) - are increasing with the quantities of trains, loading- and unloading stations in operation. Automation and integration of the train transport with loading and unloading stations but also with process control reduces directly the operational costs and delivers a number of further advantages to an underground mining operation. Main operational benefits are, for example, no need for a driver in each train, no need for operators at the loading and unloading stations or no loss in production time during shift change or blasting periods. Having everything from one single source provides benefits such as locomotives come factory fitted and tested with ATP and ATO or the train control system is already tested with loading and unloading stations in advance.

Accomplishing more together, Schalke as a specialist for mining locomotives cooperates with superior partners on joint major projects in order to concentrate expertise and benefit from synergies – and in one word, to define the state-of-the-art in fully automated high-performance rail haulage.

One particularly fine example is the already mentioned complete underground rail haulage system which Schalke has developed in collaboration with Bombardier Transportation (BT; worldwide operating and leading manufacturer of rail transportation technologies including INTERFLO 150 signaling and train automation system) and Nordic Minesteel Technologies (NMT; Ontario based manufacturer of mining cars, loading and unloading stations). Each of the three partners has decades of experience in developing and producing mining equipment. All three parties have combined their knowledge and ability to form a complete system supplied from one single source.

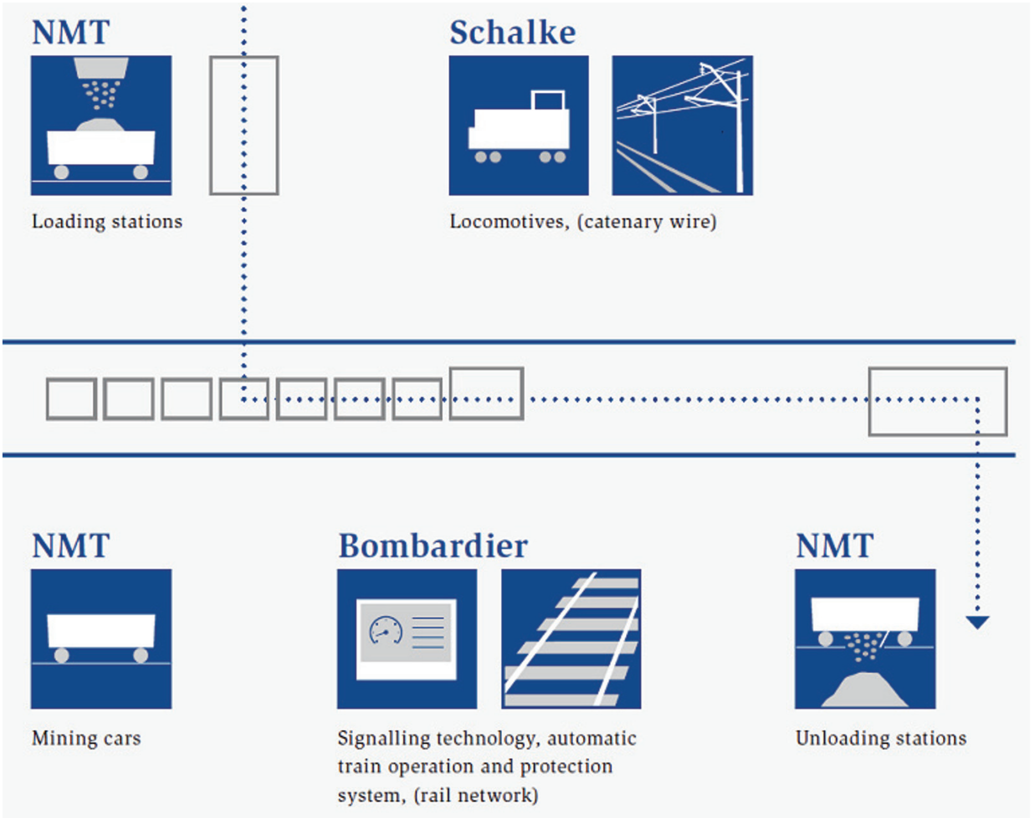


Figure 6: Proven underground rail haulage system from Schalke, NMT and BT

As shown in figure 6 Schalke provides the locomotives, BT contributes a special train signaling and automation system while NMT supplies the mining cars as well as the loading and unloading stations. The collaboration has resulted in a complete system unique worldwide that features a high degree of automation and incredible robustness. All of the system’s components are designed to withstand 25 to 30 years of continued operation. The system enables constant around-the-clock operation at high speed and maximum capacity. The automatic operation guarantees maximum effectiveness, reduced costs and increased safety underground. The -round proven robustness of the system means that the reliability is high, downtimes are minimal and operating as well as maintenance costs are extremely low in comparison to other haulage systems.

The operators of several largest mines in the world already trust in this complete system, including CODELCO's El Teniennte mines in Chile, LKAB's Kiruna mine in Northern Sweden or Freeport's Grasberg mine (under construction) in West Papua, Indonesia. Since 1996 Schalke's locomotives using BT's signaling and train automation system (including driverless operation) run underground in CODELCO's Esmeralda mine, which is a part of the El Teniennte mining complex in the Andes Mountains in Chile. The partners have nearly two decades of joint experience now. The fact that all these global players rely on the performance and quality of this system is an affirmation of Schalke's strategy of success through teamwork with customers as well as with partners.

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