Opportunities and Challenges of Rail Haulage Systems in Current Mining Operations

Rail haulage once ruled underground mining but lost its dominant position due to the flexibility and investment advantages of truck or conveyor haulage. New locomotive technology makes a strong case for returning to rail—and not just for the largest mines.

By Markus Dammers, Dr. Gregor Brudek, Matthias Pütz and Dr. Andreas Merchiers

Schalke's MMT-M-270_BDE ModuTrac locomotives are available in sizes up to 40 metric tons (mt) and feature a central cab. Each set of wheels is driven by a 135-kW AC electric traction motor. Units also are equipped with two liquid-cooled IGBT-controlled traction converters making it possible to control each set of wheels individually.

Haulage systems are a major cost driver in underground bulk mining. Current haulage technologies are continually being reviewed because these methods may consume as much as 15%–30% of the overall capital investment in a mine as well as an ever-increasing portion of operational costs. In recent decades, the increase in production by bulk mining methods has led to progress in extraction techniques, which in turn have put pressure on optimizing materials handling technology.

Until the 1970s, ore haulage was commonly carried out by rail haulage systems, which were then mostly superseded by technological progress in the form of trucks and conveyor belts.

Trucks can be used very selectively, breakdowns involving single units can easily be accommodated, and the cost of service and maintenance of DC-electric locomotives is higher than that of a diesel-driven haul truck. In addition, production processes using haul trucks have advantages over life-of-mine, because of the ease in which truck operations can be scaled up or down—it is much easier to react to variable production requirements by adding or removing trucks. However, energy consumption and air quality present significant challenges to overcome when using trucks, and large underground mines continue to evaluate practical alternatives to the use of large truck fleets and LHDs, with rail transport once again becoming a real option. Conveyor systems have also been able to gain a greater market share with the development of stronger and more cut-resistant belt coatings, but conveyors have the same flexibility issue as rail haulage.

On the other hand, ventilation is a potential benefit of rail haulage. When compared with diesel LHDs and trucks, emissions are greatly reduced, therefore the necessary ventilation infrastructure is less. This could include fewer or smaller fans, smaller or fewer ventilation shafts and drifts. In addition, rail haulage could result in smaller heading cross sections, leading to lower tunneling costs.

In summary, the use of rail systems for underground main haulage has not been entirely eliminated, with North and South America as well as South Africa and China becoming the major regions applying this technology. In commodity terms, high-capacity hard rock mines (mainly copper, gold, nickel) predominately use underground rail haulage in their production schemes, employing systems that can move 20,000 tons per day (t/d) to 160,000 t/d of material. Due to technological developments in rail haulage systems that have occurred recently, haulage with trains has become important, not only from a technological point of view, but also due to economic and environmental aspects. Especially in terms of productivity, reliability, automation and maintenance, rail haulage systems are well-suited and proven in some of the world's biggest underground mining operations such as LKAB's Kiruna mine and Codelco's Chilean copper operations.

Cost-effective Rail-haulage Solution

Generally, mining companies aim to minimize their initial capital expenditures (Capex) and mine development schedule, planning for rapid mine development to generate revenue as soon as possible. Simultaneously, they also must ensure minimal operating costs (Opex). Taking into account the typical characteristics of a rail haulage system, the results of adopting that technology would involve high initial Capex and long system assembly time, which contradict the first requirement; however, it offers great opportunities for the latter.

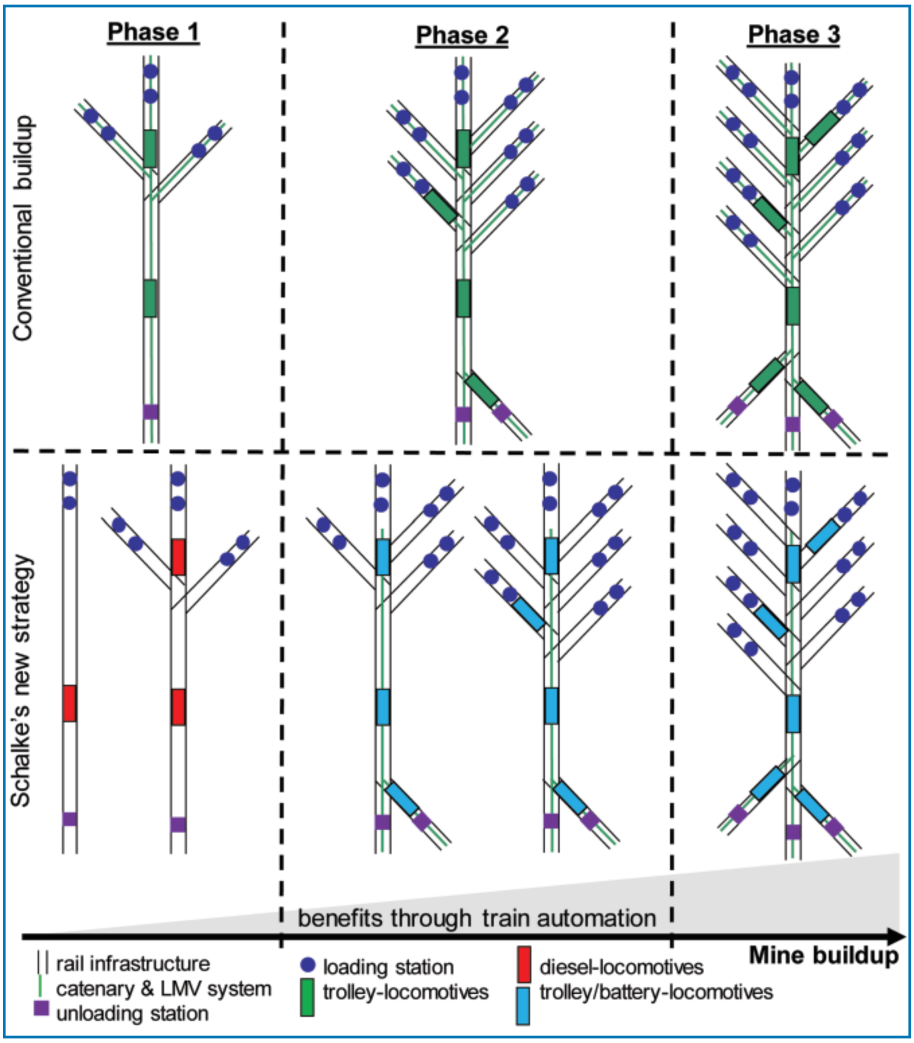
Electrical rail systems are preferred over diesel systems due to high ventilation costs and increasing environmental issues. A conventional buildup of an electrical underground rail haulage system can be divided into three phases during mine development. Typical investment requirements for these phases in conventional mine development are as follows:

Phase 1, Production Startup
- Complete main rail infrastructure, including catenary and low- and medium-voltage (LMV) system.
- First train sets (trolley-locomotives) and first loading/unloading station.

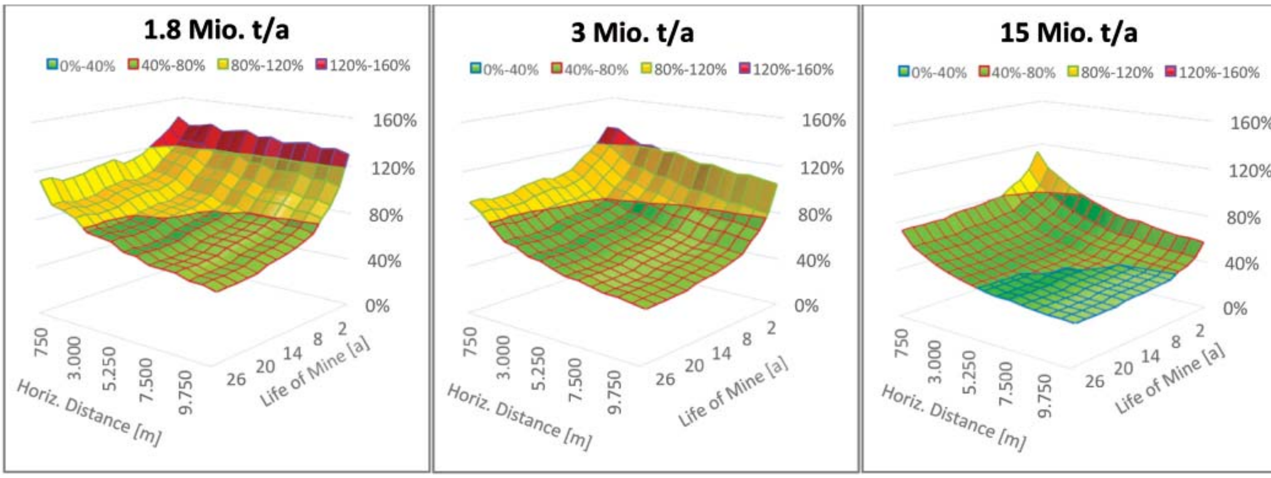
Phase 2, Production Ramp-up
- Partial extension of rail infrastructure, again including catenary and LMV systems.
- Additional train sets (trolley-locomotives) and additional loading/unloading stations

Phase 3, Targeted Production
- Complete extension of rail infrastructure, including catenary and LMV systems.
- Final train sets (trolley-locomotives) plus final loading/unloading stations.

A new strategy offered by German mine-locomotive supplier Schalke for the



Comparison of typical mine-haulage phases when employing conventional rail technology vs. Schalke's new approach.



Total cost of ownership ratio between rail and truck systems based on the horizontal transport distance and the life-of-mine for three different production scenarios.

development stage of mines minimizes the disadvantage of high Capex by using a "modular multi" system for locomotive technology, which enables early production and leads to reduced costs. Schalke's locomotives are tailor-made to handle widely varying customer requirements and are equipped with useful innovations such as exchangeable power packs. If the need arises, any of the company's ModuTrac locomotives can be converted from diesel to battery operation in less than an hour—and to other possible traction technologies as well, because of their modular design. When equipped with an additional pantograph, ModuTrac locomotives can be operated as a multimode unit. This is due to the fact that faster charging rates and other efficiency improvements in electric-locomotive flexibility and range have been made. Lead-acid battery power packs can be replaced by lithium-ion power packs, without alterations to the locomotive itself. With these new power packs, locomotives can operate much longer on battery power without recharging and, more importantly, without expensive investment in new locomotives—just the cost of new power packs. Furthermore, upgrade possibilities exist for diesel-, trolley- and multitraction power packs, e.g., battery/trolley power packs. A battery/catenary combination also significantly improves machine flexibility, allowing onboard battery charging from the overhead catenary while on the main haulage loop, switching the locomotive to battery power when it leaves the catenary during travel into development headings and loading stations.

Schalke's MMT-M-270_BDE ModuTrac locomotive, shown in the opening photo, displays features critical to the company's strategy. The heaviest twin-axle locomotive weighs 40 metric tons (mt) and is fitted with a central cab. Each set of wheels is driven by a 135-kW AC electric traction motor. It also is equipped with two state-of-the-art, liquid-cooled, IGBT-controlled traction converters making it possible to control each set of wheels individually. The locomotive features a trolley system for overhead catenary operations and a traction power pack (battery or diesel). Power packs can be changed from one mode to the other in less than an hour. This type of equipment is being implemented at PT Freeport Indonesia's Grasberg mine, which is currently in transition to underground mining.

ModuTrac technology allows for minimization of initial Capex, as well as reduced production startup schedules that result in earlier revenue generation. The three phases of the ModuTrac philosophy can be described as follows:

Phase 1, Production Startup
- Partial main rail infrastructure (no catenary and LMV system).
- First train sets (diesel-locomotive).
- First few loading stations and one unloading station.

Phase 2, Production Ramp-up
- 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).

Phase 3, Targeted Production
- Complete rail infrastructure.
- Final train set(s) plus final loading/unloading station(s).

Underground Haulage System Evaluation Model

When studying choices for the most suitable haulage system, it is necessary to analyze all advantages and disadvantages dependent on defined background conditions and to assess their economic influences within the overall context of mining operations. A computational evaluation tool, developed in cooperation with the Institute of Mineral Resources Engineering (MRE) of RWTH Aachen University, can be used to identify cost drivers of the various haulage systems when assessing the advantages and disadvantages of rail haulage for underground mining operations. The tool is useful in providing support for underground-mine project planning and for identifying technical and economic restrictions associated with implementation of different transport and haulage systems. Horizontal transportation is, in particular, one area where real potential exists for exploitation. While truck haulage has so far dominated this field of activity, the tool is able to identify the particular operating conditions in which rail haulage systems can offer a viable alternative.

In general, haulage for underground mines can be divided into two segments: 1) horizontal underground haulage and 2) vertical haulage from underground to surface. Horizontal underground main haulage is mainly carried out using trains, trucks or conveyor belts. For vertical haulage to the surface, three different methods are available: haulage by trucks or conveyor belts through a ramp or adit, and hoisting via vertical shafts.

Haulage-system performance and cost calculations are derived from mining engineering analysis fundamentals, including cycle time calculations, equipment efficiencies and personal requirements. Here, any subprocesses can be combined. The considered transportation combinations are:

- Rail + Hoist
- Rail + Conveyor
- Truck + Truck
- Truck + Hoist
- Truck + Conveyor
- Conveyor + Hoist
- Conveyor + Conveyor

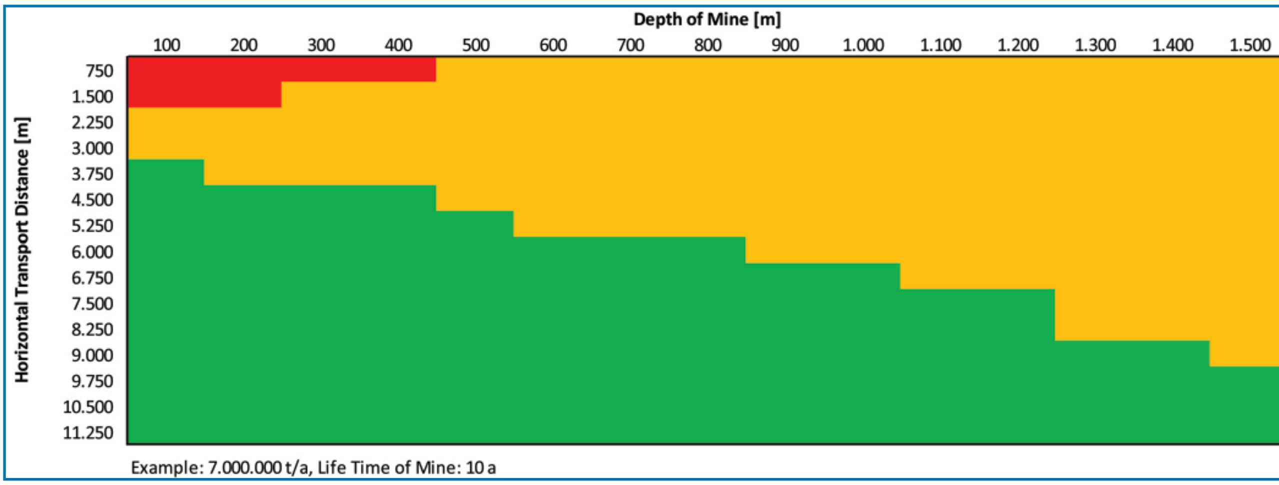
The evaluation tool uses industry-relevant cost databases and performance figures as input parameters and considers operating parameters and restrictions. Within the respective system boundaries, it is possible to draw up countless scenarios allowing the derivation of variables such as Capex, Opex and TCO (Total Cost of Ownership over equipment lifetime). The inherent advantage of implementing rail transport systems will depend primarily on the assumed Life of Mine (LOM), the annual production rate, and the length and operating depth of the horizontal transport circuit.

The graphs (at the top of page 44) show the TCO ratio between rail and truck systems based on the horizontal transport distance and the LOM for three different production scenarios. If the ratio is greater than 120%—highlighted in red—a truck system is more advantageous. The yellow sector represents threshold ratios between 80% and 120%. The rail system is preferred at ratios below 80% (highlighted in green and blue).

When variations are applied to the assumed production rates, it becomes clear—especially at low LOM—that train haulage installations can only maximize their potential advantages when lengthy operating times are involved. Their value also is enhanced by increasing horizontal transport distances. Conversely, truck systems are preferable for small-scaled mining operations with short LOM. However, an increasing production rate positively affects rail-system application limits, which can be seen by the progressive green and blue sections.

An examination of the TCO gives no more than an early indication of the benefits offered by a particular system. Finally, it is the interaction between the Capex and Opex that is the key factor for mine operators. The benefits derived on the Opex side of the balance do not necessarily result in a decision in favor of the system with the lowest TCO. The cash flow situation of the operator also has to be considered, along with the risk associated with up-front investments. Consequently, this inevitably leads to a necessary evaluation of trade-off pairs between Capex and TCO.

As an example, the scenario shown in the accompanying figure (at the top of page 46) represents a mine with an annual production rate of 7 million mt over 10 years. A comparison is drawn between rail and truck haulage systems, whereby the truck haul scenario is taken as the reference parameter. If the initial investment in the rail system is 30% higher (first threshold) than



This scenario for a mine with an annual production rate of 7 million mt over 10 years, illustrates a comparison between rail and truck haulage systems.

that of a truck-based system, and if the total cost ratio is greater than 50% (second threshold), then there is no advantage to be gained by using train transportation (highlighted in red). This will apply at shallow operating depths in combination with short horizontal transport distances.

However, if one of the above thresholds is met, it is in theory possible to apply either of the two systems (highlighted in yellow). It would then be a matter of making a decision for the particular application in question, taking into account the relevant technical and economic factors. Rail haulage systems are clearly more favorable if both threshold values can be met (green area). These trade-offs are achieved with increasing horizontal transport distances, while the influence of the vertical transport factor, which by comparison can be assumed as constant, will grow in line with increasing depth. From the other side this means the advantages and drawbacks of the horizontal haulage system will have an under-proportionate impact on the analysis as operating depths increase.

Haulage levels in bulk mining operations are particular candidates for rail systems, partly because a lot of capital is committed up front and, given the level of forward planning required, suppliers are often given LOM contracts. The obvious advantage of rail haulage in large projects is the reduced operational cost compared with the use of diesel underground trucks—rail systems have only 10% of the operational cost of trucks in some situations. Savings are maximized where rail haulage can be used to reduce manpower requirements.

Finally, by applying the evaluation tool the following general conclusions can be drawn between truck and train haulage systems:

- The higher the production volume, the more advantages accrue to rail and conveyer haulage, 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 setup.
- 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 due to a high level of automation.

In addition to these economic considerations, other factors such as health and safety, automation, sustainability and ecological impact may lead to the decision for rail haulage systems—and not only at high production volumes.

Based on the models described above, a rail system can be considered as the most suitable choice for underground haulage in many mining scenarios. Due to the technology's very low operating costs and accordingly low TCO for multiple haulage scenarios, some of the world's biggest mining companies have implemented rail haulage systems.

However, the ModuTrac solution also can be an interesting alternative for smaller applications, for replacement of existing locomotive fleets as well as for upgrades to an automated system, considering the solution's potential advantages for reducing Capex and Opex costs. For any of these instances, Schalke offers smaller locomotives in a weight range of 4-10 mt and 10-20 mt, based on the same modular design concept.

This solution—particularly in the current weak market environment where initial Capex becomes more important than the TCO and short-term concerns may overshadow long-term benefits—is seen by many as the starting point of a general paradigm shift back to rail haulage systems in underground bulk mining operations.

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