SIEMENS, J., JANSEN VAN RENSBURG, G., and VAN DER MERWE, F. Continuous loading – a safe, efficient, and productive alternative for the loading of muck at the development face. *The 6th International Platinum Conference, 'Platinum–Metal for the Future',* The Southern African Institute of Mining and Metallurgy, 2014.

Continuous loading – a safe, efficient, and productive alternative for the loading of muck at the development face

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Safe and optimal loading of muck from the face remains one of the major pinch-points and contributers to rising operational costs and inefficiency of underground mines. Rail-bound mining methods still rely on unsafe and time-consuming practices. Trackless mines loading into mine trucks and designated loading bays/niches are bound to LHDs as a matter of convention.

Development ends are constrained either by rail, space, or distance to tip points. Some see twin-end development as the predominant remedy for platinum mine deepening due to well-known factors: ventalition, logistical, and other necessities. Continuous loading can reduce development time and cost by utilizing electric power, decrease mucking time through reduced while reducing downtime, the need for tipping niches. Safety is greatly enhanced as this system reduces the risk of injury to the operator, who operates well away from the 'sharp end' of traditional loading stytems where the prevelance of hand and foot injuries and falls of ground (FOGs) is evident.

This paper will deliberate on how the development of existing technology will safely optimize productivity in small- to medium-size drifts. Addressing customer needs, the paper will explain the seamless transformation from the current slow and dangerous mucking methods to a system that is safe, continuous, fast, economical, and effective. It will also give a brief insight on the advanced level of technology applied in continuous loading for both trackless and rail-bound mining methods.

The paper will also briefly review the origin, current status, and future of this technology, and describe the various methods that may be applied to shuttle ore from the development end to the tip and their integration into various mining layouts.

The Altas Copco GIA Häggloader, working independantly with trucks, rail-bound hoppers, or as a unit loading into rail-bound shuttle cars, can achieve all of the above. This will be confirmed by actual case studies done in tunnelling and mine development projects .

Introduction to continuous loading

The unique Atlas Copco continuous loading system has proven to be highly productive, economical, and a more sustainable choice; superior when compared to other loading methods in small- to medium-sized drifts. Due to its design and compact size the Häggloader eliminates the need for loading bays, and through its high capacity it contributes in major way to completing civil/mining projects on time and below cost. The Häggloader system is designed and developed to load hard abrasive rock and can easily be matched with traditional mining methods.

Loading method

Through the system of digging arms, dozer blade, and a conveyer, material is shovelled from the rock face onto the loader's conveyer for transfer to the rock transport vehicle.

Main features and benefits of continuous loading

The main features and benefit of this continuous loading system can be listed as follows:

- The high-capacity continuous loading system reduces cycle times between rounds and eliminates the need for loading bays/niches
- Electrical operation reduces ventilation investment and running cost
- Diesel consumption is reduced and logistical issues are minimized as the unit is powered electrically. This contributes to 'green tunnelilng'. The unit is of compact design, with four-wheel (crab) steering optimized for narrow drifts and tight cornering
- Stationary position during loading reduces running cost compared to traditional loading equipment
- Excellent operator's environment and ergonomics allow for a safe and comfortable operation.

In rail-bound ends, the Atlas Copco Häggloader, perfectly matched with Atlas Copco's HäggCon shuttle car system, constitutes one single point of contact with muck.

Figure 1 shows an Atlas Copco 8HR-B Häggloader with three shuttle cars – a combination known as a HäggCom.

Technical description of a Häggloader

Two different boom applications are available on all models. Figures 2 and 3 illustrate these two configurations.

The loader is equipped with an onboard water sprinkler system to effectively control dust and explosive gas.

When digging trenches, cleaning up the tunnel prior to

Figure 1. Atlas Copco HäggCom

Figure 2. Backhoe digging arm

lining, or barring is required, the backhoe system is more useful due to the optimized bucket design.

the barring tool on the back of the digging bucket, as shown in Figure 4, is an added safety device that is being used to bar the hangingwall to remove dangerous and loose rocks.

For ordinary tunnelling, the traditional dual digging arm configuration is preferred to the backhoe configuration as it offers a 1 m^3/min higher loading capacity

A giant leap in safe mucking on the rail-bound development face

Conventional mining – rail-bound

The need to increase development rates while adhering to the principle of 'safety first' is not a new challenge. Keeping the operator under safe supported ground while loading is no longer negotiable. Enhancing the safety features on equipment to keep the operator safe from other risk factors is a priority.

The following risks are associated with pneumatic loaders (Ashworth and Peake, 1994):

- High noise levels due to the nature of air motors
- Ergonomics of the machine are such that it is difficult to see other personnel in the periphery
- Accurate control of the loader is very difficult
- The operator stands laterally on the machine, facing a control panel containing a number of levers- each one of which has a specific function. The controls are essentially pneumatic valves which, when opened, have a significant delay preceding activation of the pneumatic motors that they control (because of the air compressibility). Thus it takes a skilled operator to control the loader safely and accurately.

The operator is less than 1000 mm from the loading blade and even closer to the lashing action and the face area. Installing jump sets and temporary rails are the biggest

Figure 3. Dual digging arms

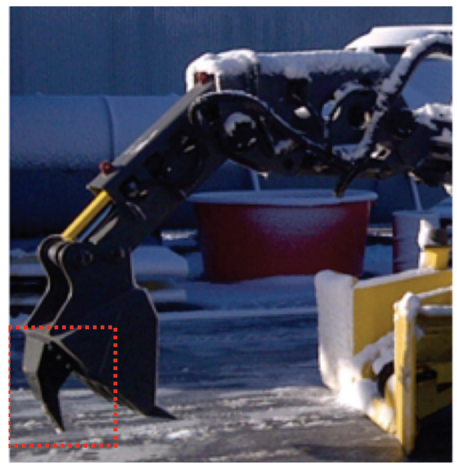


Figure 4. Barring tool

contributors to hand and foot injuries. Due to the short reach of the loader's temporary rail installation, installing jump sets is a daily task.

Another risk factor is the high-pressure pneumatic feed hose. Any break or burst in the pipe poses a great risk to personnel physically handling the hose.

In the modern labour environment, it is difficult to find people that are willing to operate lash loaders (rocker arm shovels) as this is a physical and labour-intensive job. The modern, schooled labourer prefers equipment that is more sophisticated, safe, and easy to operate.

Solutions to safety issues associated with continuous loaders

Replacing pneumatically propelled lashing loaders (rocker arm shovels) with continuous loaders reduces or eliminates the following risks:

- The noise exposure levels experienced by the operator are much reduced. The only audible noise associated with the continuous loader is the movement of blasted rock as it is shovelled onto the conveyer feed and transferred via the conveyer discharge chute into the hauling vehicle. As the unit is electrically powered, the noise level is in an acceptable range
- Ergonomics are designed with operator safety first in mind. The operator stands on an elevated platform and is secured to the unit with a safety belt. The controls are two joysticks with a very soft feel and direct action. All actions, both propelling and operating the digging system, are done with the two joystick levers
- The operator is several metres away from the mucking

and protected from falling objects under a 'FOPS' approved canopy. Even on longer advances the Häggloader will be able to clean the face without exposing the operator to unprotected ground
- With a reach of 3950 mm and the ability to handle jump sets with the hydraulic digging arm or backhoe, the Häggloader is fast and safe. Temporary rail sets are placed hydraulically in front of the dozer blades and the Häggloader simply pushes the rail into the muck pile. No personnel are required to be in front of the unit near unprotected ground.
- The unit may be diesel powered for transportation purposes, adding to its versatility
- Minor digging can be performed on diesel power.

With the Häggloader 9 HR, a crawler-mount unit, no temporary rails are needed and any kind of manual temporary rail installation is eliminated. The unit is specially designed for muddy and tough conditions. It is equipped with a pony track wheel system that allows the unit to raise itself onto the rail tracks for transportation to and from the work area (Figure 5).

Fast continuous mucking of trackless development ends

In larger excavations where trackless mining methods are used, the rubber-tyred 10HR is easy to maneuver thanks to the four-wheel-drive with separate steering of front and rear axle. With the unique 'crab steering' the loader can actually move sideways and load in wider ends without having to go through a number of forward/reverse positioning maneuvers.

With the larger loader's loading capacity of up to 5 m^3/min, tunnel/drift sizes up to14 m^2 can be cleaned quickly and efficiently.

The hydraulic system is powered by the electrical power pack. Due to the hydrostatic drive train, re-positioning can be done in both diesel and electrical mode.

The operator´s position is in a safe and well-protected FOPS-approved cabin with good overall vision. On the rubber-tyred 10HR, operator ergonomics are of the highest standards to ensure safety and comfort and thus sustainable productivity. A comfortable driver seat with armrest-mounted joysticks reduces operator fatigue. An airconditioner and heater provide good working environment. Protection bars at the widows keep the operator safe. An LCD panel with all data information and two different camera views for optimized loading and safety are standard features (Figure 6).

Hauling methods

There are three suggested methods of hauling muck from the continuous loader to the desired niche:
- HäggCom rail-bound shuttle cars
- Perfectly matched mine trucks
- Mining hoppers – various sizes.

HäggCom rail-bound shuttle cars

To keep up with the continuous feed from the Häggloader, shuttle cars are used on rail-bound applications. Although operating conditions vary from mine to mine, development drifts seldom exceed 1000 m in length, meaning that the haulage may be carried out with one or two shuttle cars per level. The shuttle cars can be used either as a single car or connected together to form a train, moved by a locomotive.

The shuttle car consists of a car body mounted on two bogies. Running along the bottom of the car is a chain conveyor, which is driven by electrical motors. The conveyor, which is a type of flight conveyor, consists of two roller chains to which a number of flights are attached. With the aid of the flights the blasted rock is moved forward in the car for loading, load transfer, and discharging.

The conveyor drive is mounted in a cradle behind the front bogy. These motors drive the conveyor chain via dual roller chains, propeller shafts, and worm gears.

The standard car body is an all-welded unit-type structure build to extremely heavy-duty specifications. The body can be supplied in sections to accommodate lowering down narrow shafts.

The frame of the car body consists of steel beams USP-100, 120 and also pressed U-section steel members. Bottom plates of 8 mm and 15 mm sheet steel are welded to these steel members. A wear layer of 12 mm HARDOX 500 wear plates is welded onto the bottom plates.

The sides of the wagon body are made of 10 mm sheet steel reinforced with longitudinal mouldings and vertical stiffeners. The insides are fitted with shaped wear plates at the narrow part of the body.

Haulage methods

When selecting the optimal HäggCom for a specific site the following combinations or methods must be considered.

Figure 5. Crawler-mount lifted onto pony tracks

Figure 6. Operator's cabin

Single shuttle car with continuous loader:

This method is recommended for mines with rail systems developed for hopper transport (Figure 7).

Haulage by one bunker and one train car:

This method is recommended for mines with rail systems developed for hopper transport (Figure 8).

Haulage by one bunker car and two or more train cars (Figure 9)

Haulage of entire round by one shuttle train (Figure 10)

Traditional mine hoppers

The Häggloader fills the hoppers and the hopper train is utilized in the same manner as the traditional air loader system.

For this method conventional rail systems can be used where spurs (previously referred to as niches or loading bays) are used for the swopping of loaded hoppers (Figure 11).

Perfectly matched mine trucks

When selecting a continuous loader to match mine trucks, the length of the conveyor is critical to ensure minimal spillage and fast seamless changing between loader and empty trucks. Depending on the truck size, the length of the conveyor should be customized (Figure 12). The high of the discharge end of the conveyor is just as important as the selected truck should be able to fit underneath the discharge end.

Discount production time and cost

Actual customer savings

The Häggloader concept can significantly reduce operational costs (Figure 13). Calculations prove that the previous mentioned benefits lead to actual customer value in the following areas:

- Continuous loading without interruption
- Higher productivity in medium and small tunnel sizes
- Reduced ventilation costs
- Less manpower
- Reduced need for niches.

Case studies

Rail-bound mechanized footwall development

Impala Platinum 20 Shaft – 21 North Drive off-reef development.

Project details	
Client/owner:	Impala Platinum, 20-Shaft
Contractor:	Triple-M Mining
Project manager	Johan de Klerk

For the purpose of this paper, only the cleaning and transportation of the broken rock will be extracted from the full report

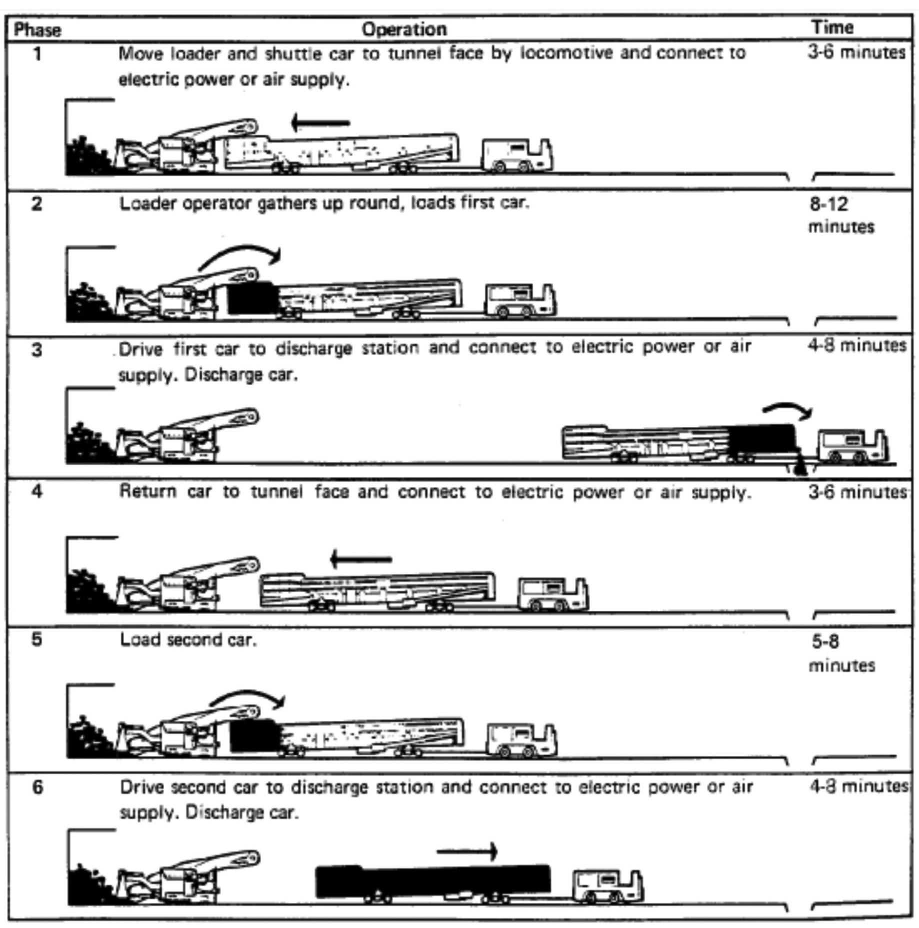


Figure 7. Single shuttle car with continuous loader

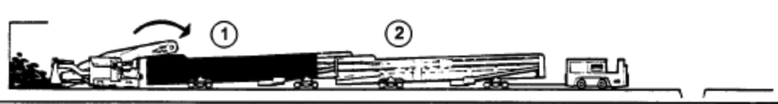
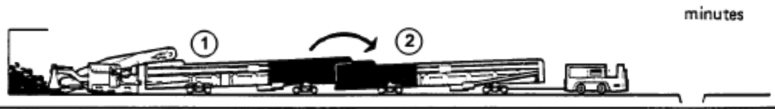
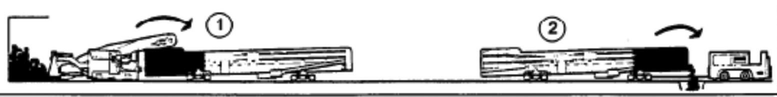
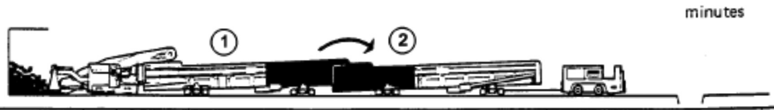
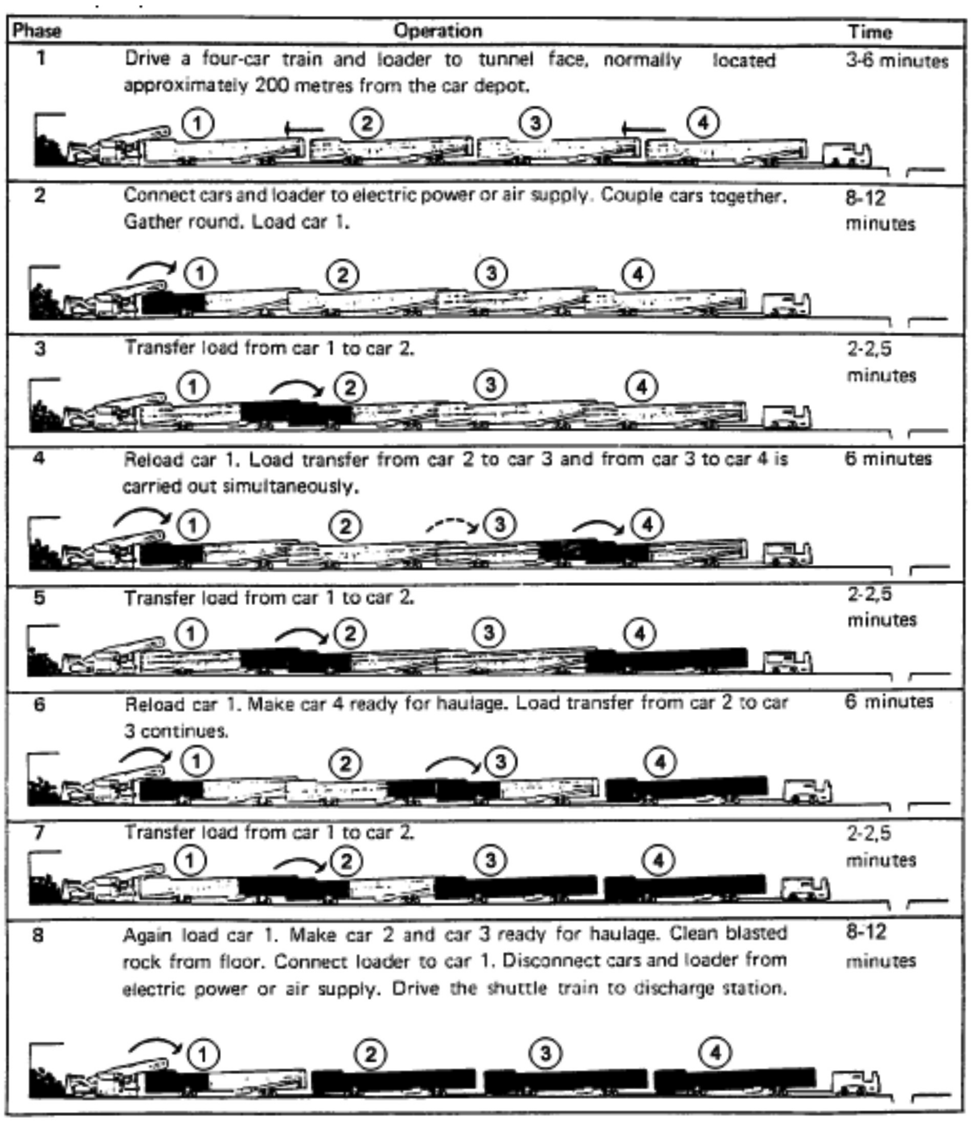
Phase	Operation	Time
1	Drive two cars and loader to tunnel face, normally located approximately 200 metres from the car depot. 	3-6 minutes
2	Connect cars and loader to power or air supply. Couple cars together. Gather round. Load first car 1. 	8-12 minutes
3	Transfer load from car 1 to car 2. 	2-2.5 minutes
4	Reload car 1 while car 2 is driven to discharge station for emptying and return to the tunnel face. 	5-8 minutes
5	Transfer load from car 1 to car 2. 	2-2.5 minutes
6	Load car 1 again. Meanwhile, drive car 2 to discharge station for emptying and return to the tunnel face before car 1 is fully loaded. 	5-8 minutes

Figure 8. Haulage by one bunker and one train car

Phase	Operation	Time
1	Drive two cars and loader to tunnel face, normally located approximately 200 metres from the car depot. 	3-6 minutes
2	Connect cars and loader to electric power or air supply. Couple cars together. Gather round. Load car 1. 	8-12 minutes
3	Transfer load from car 1 to car 2. 	2-2,5 minutes
4	Reload car 1 (twice, with load transfer). While car 1 is being loaded, drive car 2 to discharge station — 2000 metres in 7 minutes — discharge in 2 minutes and return to siding — 1000 metres in 3 minutes. Car 3, now loaded, waits on siding for haulage. Car 2, now empty, continues 1000 metres to tunnel face in 3 minutes. Total time 15-16 minutes. Meanwhile, bunker car has been loaded in 5-8 minutes and its load transferred to shuttle car in 2-2.5 minutes. Bunker car is again loaded, in 8-12 minutes. Total time taken is 5-8 + 2-2,5 + 5-8 = 12-19 minutes. Shuttle car 2 returns to tunnel face in good time to permit a continuous loading operation. 	12-19 minutes

Figure 9. Haulage by one bunker car and two or more train cars



Phase	Operation	Time
1	Drive a four-car train and loader to tunnel face, normally located approximately 200 metres from the car depot.	3-6 minutes
2	Connect cars and loader to electric power or air supply. Couple cars together. Gather round. Load car 1.	8-12 minutes
3	Transfer load from car 1 to car 2.	2-2,5 minutes
4	Reload car 1. Load transfer from car 2 to car 3 and from car 3 to car 4 is carried out simultaneously.	6 minutes
5	Transfer load from car 1 to car 2.	2-2,5 minutes
6	Reload car 1. Make car 4 ready for haulage. Load transfer from car 2 to car 3 continues.	6 minutes
7	Transfer load from car 1 to car 2.	2-2,5 minutes
8	Again load car 1. Make car 2 and car 3 ready for haulage. Clean blasted rock from floor. Connect loader to car 1. Disconnect cars and loader from electric power or air supply. Drive the shuttle train to discharge station.	8-12 minutes

Figure 10. Haulage of entire round by one shuttle train

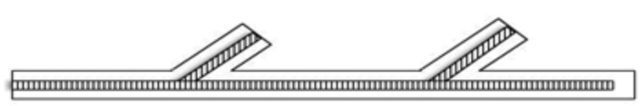


Figure 11. Schematic rail outlay for loading into hoppers

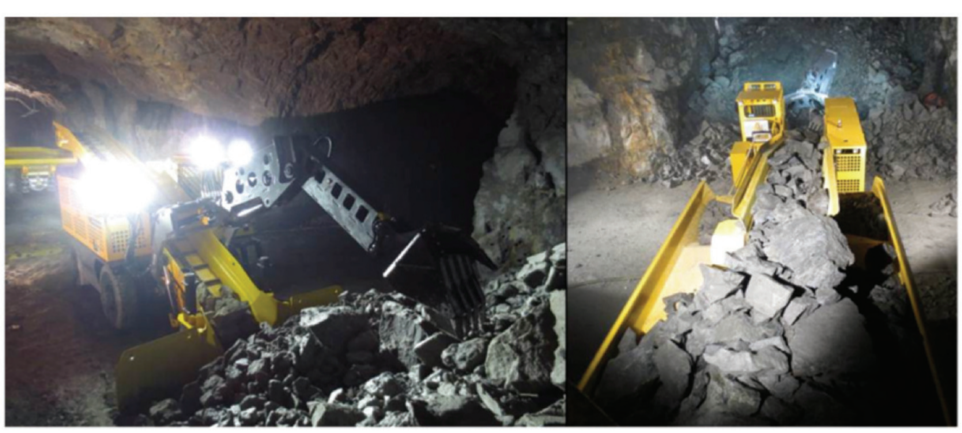


Figure 12. Continuous loader filling a mine truck

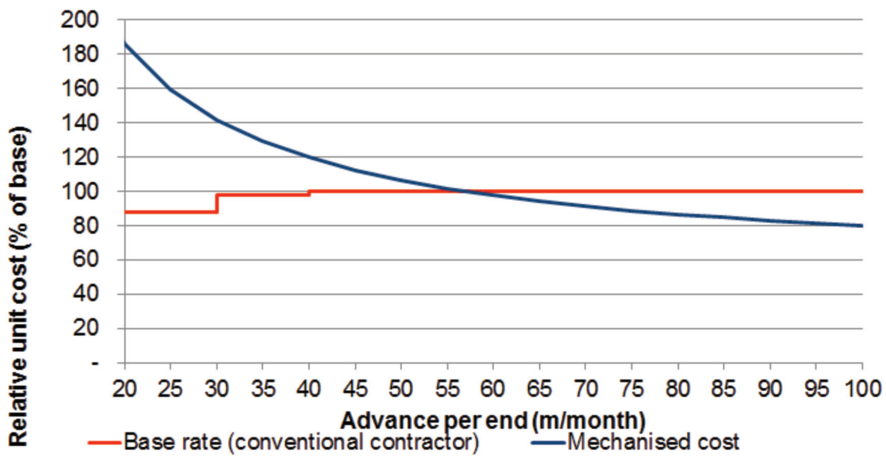


Figure 13. Actual cost saving utilizing a mechanized drill rig and a continuous loader

Project objectives

OBJECTIVES	1	To demonstrate the technical feasibility of rail-bound mechanized development, following the same development cycle, currently utilized at No. 20 Shaft in the trackless decline and incline spines.
	2	Determine key cost and performance parameters.
	3	Reduce the risk of exposure to FOG accidents by removing personnel from the face area of footwall drive development during high-risk activities, such as barring and support drilling and installation.

Evaluation against objectives

1	To demonstrate the technical feasibility of rail-bound mechanized development, following the same development cycle, currently utilized at No. 20 Shaft in the trackless decline and incline spines.
	The method is feasible and the equipment, required is commercially available.
2	Determine key cost and performance parameters.
	Achieved
3	Reduce the risk of exposure to FOG accidents by removing personnel from the face area of footwall drive development during high risk activities, such as barring and support drilling and installation.
	Achieved

Development end dimensions

The mining layout for the trial area followed the standard Impala half level layout, with lay-byes for access to the reef horizon. However, the tunnel dimensions were increased to 4.0 m x 4.0m to accommodate the equipment and the specified support methodology of split sets and mesh.

Loader

Although the overhead pneumatic loader (OPL) or rocker shovel is well-proven and popular with mining personnel, it suffers the following limitations in respect of rail-bound mechanized development:

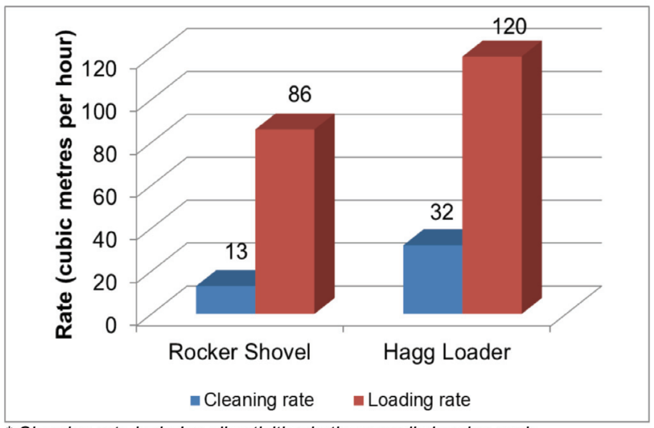
- With the overall length of a standard LM57 loader being 2.35 m, the operator is relatively close to the muck pile, resulting in exposure to unsupported ground, when longer rounds are drilled and blasted. For this reason, the advance is limited when using a rocker shovel. Attempts to produce a remote-controlled rocker shovel have had limited success, primarily due to the fact that a sufficiently-robust camera to provide operator visibility of the loading operation has not been found
- The motion of the loader often leads to derailments in the face and potential risk of injury to the operator
- The loading rate is limited, as shown in the comparison below.

A readily available alternative to a conventional rocker shovel is a continuous/mucking loader, which offers the following potential advantages:

- A longer digging reach, which means the operator, is located further back
- Loading is performed by digging arms/paddles or a backhoe mechanism, feeding onto a chain conveyor and is therefore inherently more stable and less prone to derail
- The continuous loader offers significantly higher loading and cleaning rates, as shown in Figure 14.

The loading rate with a continuous mucking loader is dependent upon the loading mechanism, with the paddle-type arrangement shown in Figures 15 and 16 generally yielding higher loading rates than a backhoe arm, shown in Figure 17. The backhoe arm is particularly limiting when large rocks are being handled, which reduces the loading rate significantly. For example, Atlas Copco quote a loading rate of 180 m^3/h for its 8HR Häggloader when fitted with a paddle-type loading arrangement. The rate is down-rated to a range of 120 – 180 m^3/h when fitted with a backhoe loading mechanism. The main advantage of the backhoe loading mechanism is greater versatility in terms of the following:

- Reach to load from cubbies
- Ability to bar with the bucket or a scaler fitted to the bucket.



** Cleaning rate includes all activities in the overall cleaning cycle*

Figure 14. Cleaning and loading rate comparison (source: results from Deep Mine Project)

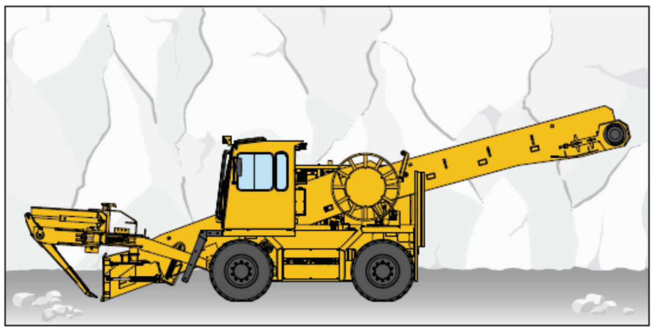


Figure 15. Mucking loader with paddle arms, tyre-based (Atlas Copco)

The loaders are also produced in rubber tyre, rail-bound, and dozer track configuration.

The system utilized in the trial at No. 20 Shaft was an 8HR rail-bound Häggloader from Atlas Copco, fitted with paddle arms to facilitate a high loading rate, as shown in Figure 18.

The cleaning rate is dependent on both the loading rate of the mucking loader and the rate at which rock can be trammed to the tips. It is therefore common in high-speed development applications to utilize a set of shuttle cars (Figure 19) as shown previously, in combination with a mucking loader.

Conclusions

The trial demonstrated that the method, currently used for the trackless incline/decline development at No. 20 Shaft, can be implemented for footwall drive development, utilizing rail-bound equipment. The method effectively removes personnel from the face area during all activities, except mark-up and charge-up, and is therefore inherently safer. A rate of advance of at least 60 m per month is achievable (De Wet, 2013).

Holsbru Kraftverk Project, Norsk Hydro, Norway, 2011

Project details

Tunnelling contract:	US$36 million
Client/Owner:	Norsk Hydro
Contractor:	Haehre Entrepenor

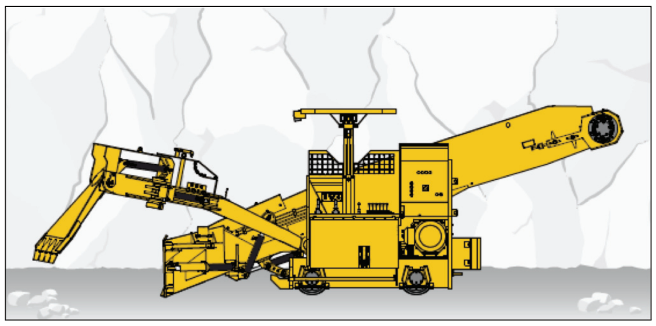


Figure 16. Mucking loader with paddle arms, rail-bound (Atlas Copco)

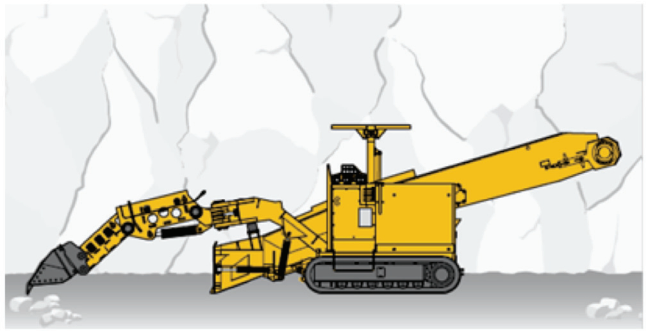


Figure 17. Mucking loader with backhoe arrangement, crawler-based (Atlas Copco)

Figure 18. Häggloader underground at No. 20 Shaft

Figure 19. Shuttle car (typically three or more are used with a Häggloader

Site Manager:	Emst Ove Johansen
Site Engineer:	Elisabeth Holsbrekken
Engineering Consultant:	Multiconsult, Norway

Norwegian hydropower producer Norsk Hydro is building a new feeder tunnel to increase feed to the existing Holsbru Kraftverk project in Sogun country, 300 km northwest of Oslo.

The drill and blast part of the tunnel complex will be 6000 m tunnels, 4 m x 5 m high. Overburden will be 40-50 m while the head at the power station will be about 740 m.

The tunnels are excavated at multiple faces simultaneously, with around three drill and blast cycles per face per day, each blast resulting in a 4.0 to 4.5 m advance. An Atlas Copco GIA 10HR-B electro-hydraulic trackless Häggloader is used to scoop the spoil onto a conveyor system feeding the trucks without the need of any loading system (Figure 19).

Once the face is clean, the Häggloader is driven to the next end with the onboard diesel engine.

According to Mr Emst Johansen, the site manager, the Häggloader can clean the face in only 2 hours, loading between 20 and 25 dump truck loads in the process. Mr Johansen told World Tunnelling: 'The Häggloader may be a fast unit, but is also very good for emissions as it is a clean machine, which is important if you are working in a long tunnel. In addition the clean environment means less ventilation is required. Typically loading rates are 3-4 m^3/min, which is very fast as the Häggloader fills the dumper trucks continuously trough the chain conveyor' (Demitri, 2011).

GIA Häggloader produces zero carbon dioxide emission

'Norwegian tunnelling contractor Haehre Entreprenor is making fast progress with reduced carbon footprint at Holsbru Kraftwerk power project near Ovre Ardal. The 6 km-long x 20 m^3 drill/blast tunnel is being mucked out on two faces by a wheeled Atlas Copco GIA 10HR-B Häggloader electro-hydraulic backhoe loader (Figure 20) achieving 3-4 m^3/min with zero carbon dioxide emissions. Loading is faster, and ventilation requirements are less than for diesel loaders.' (Chadwick, 2009).

Figure 20. GIA 10HR-B Häggloader electro-hydraulic backhoe loader at Holsbru Kraftwerk power project (International Mining)

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