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Electro-Monorails — An Alternative Operating System for Deep Mining

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Abstract

The need to develop innovative responses to the challenges posed by mining at depths below 600 m has been recognised. The large excavations associated with current underground bulk mining practices are unlikely to be geotechnically and economically sustainable in these conditions. The heat load and airborne exhaust contaminants emitted by large diesel engines working at these depths can create unacceptable demands on mine ventilation systems resulting in substandard working conditions.

This paper proposes the adaptation of existing monorail technology using continuous conductor technology to provide competitive haulage rates in substantially smaller access excavations at steeper grade that is currently achievable. It is additionally proposed that a suite of equipment can readily be sourced to enable development of these excavations supported by the monorail system. As a capital cost optimising approach it is suggested that the electrical conductors associated with the monorail form the second level electrical reticulation for the mine workings.

1 Introduction

"Safe and viable strategies must be developed. This may be difficult for some deep mines, especially if old technologies and thought processes continue to be used. The WA Mining Industry needs a well-funded, enthusiastic, energetic and optimistic culture (organisations, companies and people) to trial and apply new solutions".

So ends a paper presented by Lee et al. (2001) entitled 'The High Stress Challenge Western Australian Mines". The document describes the stress related issues which are likely to confront mining companies who wish to operate in the Yilgarn Craton at depths greater than 600 m. The message is clear; the large access excavations typical of many Western Australian mines are likely to be unsustainable at those depths, from both geotechnical and economic perspectives. At the time that paper was published the average cross sectional area of a typical decline or main haulage was a nominal 5 x 5 m. Since then the popularity of the 5.5 x 5.5 m cross section has risen and in some instances even larger openings are in use. Perhaps surprisingly there are not many reports of difficulty in working with these excavations, possibly indicating that progress in rock reinforcement technology and support strategies has overcome the anticipated problems. Much has indeed been achieved, but at significant financial cost. Metal prices in the current resources boom have helped to offset this and although the good times are expected to continue, a downturn could find many operations exposed.

2 The diesel 'trackless' option

A distinguishing feature of modern underground 'hardrock' mines in Australia is their seemingly invincible dependence on diesel; rubber tyred machinery based mining methods. This 'system' has attained iconic status in certain quarters and it must be acknowledged that the model has in the past served, and in some cases continues to serve, the industry well and will be difficult to displace. It is nonetheless this reliance on big mobile equipment underground that gives rise to the large excavations in question. The 'High Stress Challenge' paper points out that the then classic 5 m wide by 5 m high access tunnels, *"effectively have lower rock strengths, compared with the smaller openings previously used"*. Bigger cross sections simply exacerbate the geotechnical problem.

The problems associated with 'large' excavations at depth are well known. There is elevated seismic risk, an increased likelihood of large unstable blocks forming, and falling from higher positions, having the potential to cause major damage and injury. Heat pick-up from the greater surface areas exposed can require the circulation of large volumes of ventilating air, a cost factor often obscured by the overarching ventilation demand of providing sufficient air to cool diesel engines operating underground and simultaneously maintaining adequate breathing air quality.

Other threats exist to the use of diesels. It is widely accepted that we are passing through the second 'Hubbert Peak' in petroleum production, if indeed we are not already on the post peak decline. Dr. M. King Hubbert was an American petroleum geologist who correctly predicted that US domestic oil production would peak in the early seventies and thereafter the country would become increasingly dependent on imported oil. Hubbert's successors, using his methodology, have similarly predicted that world oil production would peak post 2000 and then decline (Figure 1). Events in the petroleum arena lend certain credence to this view.

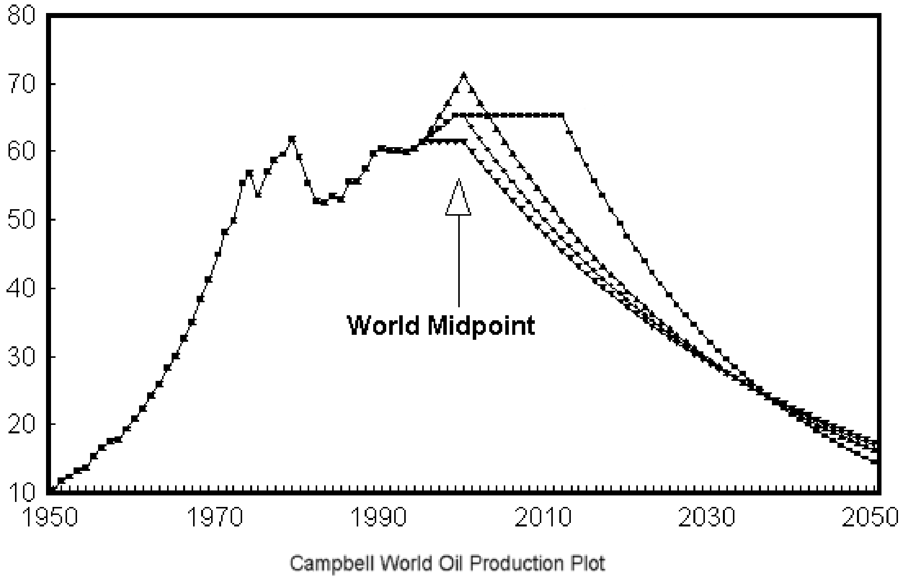

Figure 1 Extrapolation of World Oil Production post 2000 (http://www.hubbertpeak.com/)

This effectively means that the current high oil prices are unlikely to retreat. Crude oil is the source of diesel fuel but it is also the source of the synthetic rubbers used in tyre manufacture, which is another pillar of so-called trackless mining methods. The current situation regarding the availability and cost of earthmoving tyres does not need to be highlighted.

Diesel powered mobile machinery, particularly the equipment used in mining, with all the flexibility it affords mine designers and operators, its ease of operation and convenience, is not very fuel efficient. The physical demands placed upon the vehicles require a level of robustness which translates to very heavy construction. Similarly the design of transmission systems used has a greater focus on durability than efficiency of energy transfer. In spite of all this, mobile machinery used underground appears to carry a greater maintenance impost that its surface equivalent.

The above comments notwithstanding, it must be acknowledged that great strides have been made by the manufacturers of diesel engines and transmission systems over the last 15 or so years in the area of operational efficiency and specifically in terms of fuel efficiency. A major component in this progress has been the incremental improvements in the reduction of noxious exhaust gas emissions. Unfortunately the very engines which exemplify this progress now stand accused, admittedly on thin evidence, of producing polycyclic aromatic hydrocarbons, or PAHs, some of which have been identified as aggressive carcinogens. Legislation regarding PAH production in confined atmospheric environments such as underground mines is being considered in a number of countries including the USA. It is another challenge to the use of diesels underground.

The final challenge worthy of mention is that of ‘greenhouse’ gas emission. This, we are told, has humanity staring catastrophe in the face and it must be eliminated. Irrespective of one’s personal view of this, and the writer holds himself as a sceptic, the protagonists of ‘global warming’ now hold the high ground and woe betide the mining company, transport operation or power generating enterprise who fails to assiduously pursue the reduction of carbon dioxide emissions from their respective processes.

3 The ‘electrical’ option

Electrically powered ‘trackless’ machinery has been around for a very long time. Most mining people are at least aware of the iconic ‘Kiruna Truck’, and rubber tyred loading machines or ‘boggers’ operating off a ‘trailing’ cable are relatively common in hardrock mining. Whilst eliminating some of the heat transfer and all of the exhaust emission issues associated with diesels, these machines still suffer from the problems of grade ability and tyre wear typical of diesel trackless equipment. Their rock digging and carrying capability closely reflects that of their diesel powered cousins and the use of electricity carries a significant infrastructure cost. There is another option.

4 Objectives of change

The following are some of the objectives of changing to smaller, electrically-powered equipment:

- Geotechnical - reduction of excavation dimensions:
    - Less seismic risk.
    - Lower support costs.
    - Lower ventilation costs.
    - Lower excavated rock volumes.
    - More effective inspection regimes and economic remediation.
- Transport:
    - Elimination of diesel powered equipment underground by replacing it with quasi-mobile mains powered electrical transport and development methods.
    - Provision of more a effective transportation system.
    - Ease of access equivalent to existing ‘trackless’ methods.
    - Ability to move equivalent or greater tonnages in substantially smaller excavations.
    - Use extant equipment, if necessary, modified, to achieve the above.
- Ventilation:
    - Maintain appropriate airflows using smaller volumes.
    - Move to a parallel ventilation model.
    - Eliminate diesel exhaust fumes and associated airborne contaminants, e.g. PAH.
    - Reduce creation of dust.
    - Reduce heat load in underground workings.
- Energy Source:
    - Remove heat engines from the underground environment.
    - Use ‘mains’ sourced A.C. power.
    - Second level electrical reticulation is an integral part of transport system.
    - Facilitate automation.

- Operation
    - Reduce quantity of rock requiring to be mined.
    - Improve grade control by reducing external waste mined.

5 The proposal

To replace the non-shaft component of the mine transport system with roof/backs mounted monorail which provides mobile motive energy whilst simultaneously functioning as the second level electrical reticulation system. Such an arrangement, by employing ‘mains’ electrical power in a mobile or at least ‘quasi mobile’ manner, can provide a solution to some, if not all, of the challenges identified above. An electro-monorail, combined with currently available drilling, supporting and loading equipment offers a means whereby this may be achieved. It must be stated at this point that monorail haulage is not necessarily being proposed as a total replacement or direct competitor to the large tonnage autonomous machines currently in use, although that capability does exist and can be implemented if appropriate. Research is being done at the Western Australian School of Mines into the application of monorail haulage systems in metalliferous underground mining (Chanda, et al, 2004).

Overhead monorail haulage has been in existence for a very long time. An example, dating from the late 1800s can be seen at Wuppertal in Germany, supported on trusses above the Wupper River (Figure 2). Monorails powered by rope, battery and diesel have been used extensively in underground coal mines, particularly in Germany. The Electro-monorail is so called because it combines the ‘I’ beam steel support rail with the sliding electrical pick-up contact arrangement commonly used on overhead cranes. The manufacturers of these electrical components have enhanced their systems to permit relatively high speed operation and provide the capability to handle large current and high voltage. Arguably one of the most famous applications of this technology was providing motive power to the trains removing spoil from the tunnel borers cutting the Channel Tunnel.

Figure 2 The monorail at Wuppertal

The monorail system was conceived and developed in the European underground coal industry over many years, during which time safety devices and procedures reached a high degree of refinement. A difficulty with using the electro-monorail equipment in coal mines arises because the mobile pick-up sliding along the current rail generates a continuous electric arc. Regulatory authorities with responsibility for underground coal mines view this as a potential ignition source if methane is present and have consistently opposed its introduction to that environment. Although methane and its sister hydrocarbons do indeed occur in some ‘hardrock’ mines the risk profile is very low, primarily due to the volumes of air circulated. Since the concept of electro-monorails was introduced in South Africa in the early 90s twenty-three of these systems have come into operation, one of which is a locally produced machine.

The monorail system, as originally conceived, provided a means of moving relatively heavy loads into and out of the restricted workspaces typical of many of the European coal mines. It was occasionally used to move the mined material, but its unsuitability as a large volume carrier of relatively light material inhibited its widespread use in that way. A relatively old example is a large ‘chock’ or ‘prop’ being brought into the working area on a cable operated monorail (Figure 3).

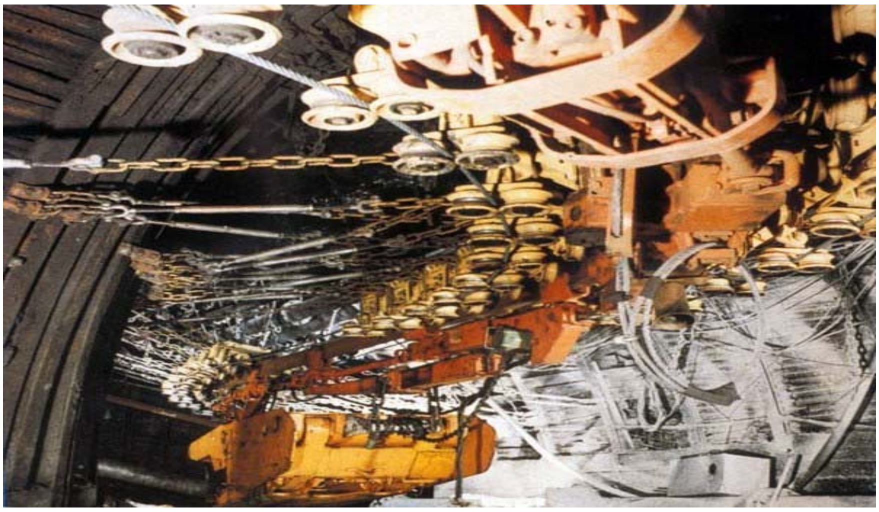

Figure 3 A large hydraulic chock/prop being transported on a cable powered monorail

A monorail works in a manner very similar to the classic mine rail transport systems which are familiar to our older colleagues. In this it shares many of the advantages of floor mounted rail, but overcomes the bulk of that system’s limitations. Pre-eminent amongst its capabilities is the ability to negotiate grades up to 36º and vertical and horizontal curves of 10 m and 4 m radius respectively. This is a function of the drive system which is based on hydraulically loaded ‘tyres’ which bear on the ‘I’ beam web. When exceptionally steep grades have to be negotiated a seamless transition to a rack and pinion arrangement is effected. An inherent safety feature is a braking system which also acts on the ‘I’ beam web and is spring applied in the event of power being lost. Normal service braking is carried out by putting the electric motor into regenerative mode, sending power back into the system (Figure 4).

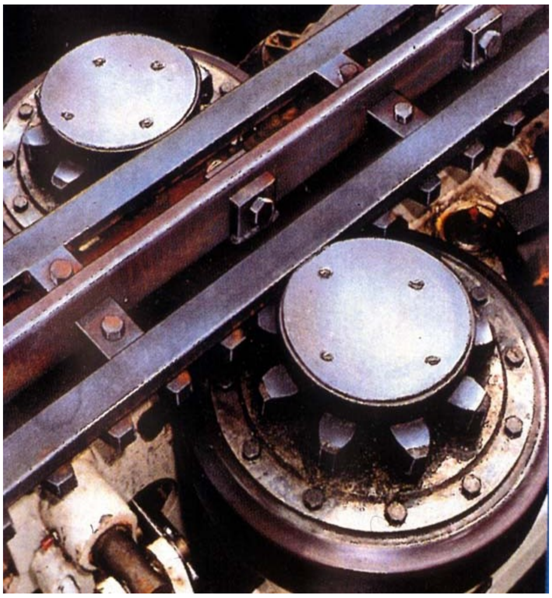

Figure 4 Monorail hydraulic drive units showing ‘tyres’, rack and brake attachments

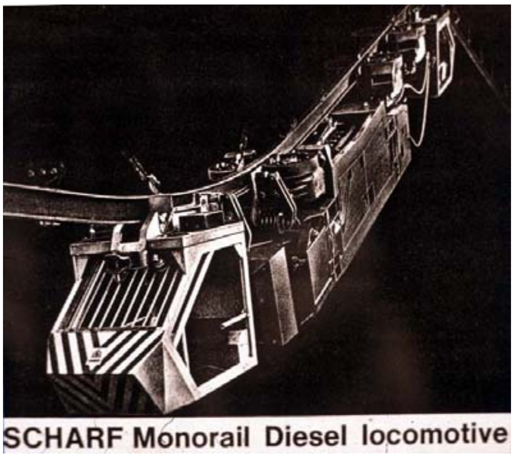

Figure 5 A diesel monorail locomotive coming off a steep incline

The machine shown in Figure 5 is a locomotive, which has an independent power pack and pulls or pushes a span of ‘tubs’ and their carriers. The number of tubs which can be moved and the ability of the unit to climb inclined sections of rail are thus dependent on the power of the prime mover. An electro-monorail offers the possibility of using multiple drive modules and there is no loco to reduce effective payload. Tonnage capability is mainly limited by the current carrying capacity of the conductors. This in turn is affected by the applied voltage, which with modern protection systems can be quite high and still be safe. Voltages in the region of 3.3 kV are possible, which can offer excellent payload performance. It must be emphasised at this stage that unless the employment of higher voltage supply is accepted the electro-monorail is unlikely to ever achieve its potential as a bulk transport system.

The conductors are similar to those used on the travellers of overhead cranes (Figure 6). The current collectors, i.e., the moving component, are made of a wide range of materials to ensure suitability for every application and environment. The insulation, in terms of material and configuration conforms to the European ‘finger protection’ standards (Figure 7).

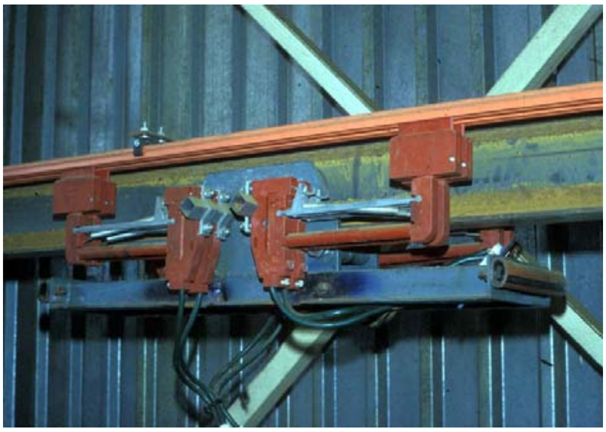

Figure 6 A monorail conductor and current collector arrangement with safety guards removed

Figure 7 Polyethylene insulation and a 4 mm. aperture ensure no inadvertent contact with live conductors can occur

The basic component of monorail infrastructure is the rail assembly. In an extensive system this is likely to constitute the largest capital cost. The current rating on the conductors on an electro-monorail can be specified to be very much greater than that required for the transport function, providing a means whereby electricity can be reticulated to all working areas. The design of the conductors and the insulating housings includes ‘take-off’ points from which lighting, fans; pumps etc can receive power without hindering normal monorail usage. A typical layout would be main mine cable reticulation based on 6.6 kV feeding transformers which in turn would feed the monorail at 1000 V. In this way some of the expense related to the monorail infrastructure can be shared by that of electrical reticulation. The construction of the individual monorail segments is robust and wear on the components is low. They are completely re-usable and the task of installation is comparable to hanging service pipework. The rock reinforcement elements commonly used in mines such as friction stabilisers and grouted bolts provide sufficient carrying capacity for the system.

The fact that the electro-monorail draws its energy from a generator on surface eliminates most of the ventilation difficulties associated with diesels in the underground workplace. The electric motors do emit heat but in proportion to the work carried out it is far less than an equivalent diesel. There are other benefits however. Western Australia is well provided with natural gas and although the reticulation system is far from comprehensive, a great many mining operations have access to electricity produced by modern high performance gas turbine generator sets. This clearly eliminates diesel fuel related issues but it is acknowledged that this method produces less greenhouse gas per unit than diesel dependent generation.

6 Ancillary equipment

One of the perceived drawbacks of the adaptation of monorail technology to the needs of the Australian underground hardrock mining industry is that it is only a transport system which cannot currently be used to create the excavations in which it must operate. The results of a project carried out at the Western Australian School of Mines to compare a diesel/rubber tyred based system with one based on off the shelf monorail technology illustrates this problem very clearly. The lack of suitable drilling and cleaning equipment leads to diesel/rubber tyred machinery being employed to develop the excavations for the monorail, which results in any advantage deriving from the use of the latter being largely compromised.

A suite of drilling, charging, cleaning and rock reinforcement equipment will have to be developed which is capable of operating from the monorail system and will suit the smaller excavations used. Modern rubber tyred drilling equipment is largely modular in construction, composed of carrier, electro-hydraulic power pack and the drilling ‘end’. Figure 8 shows a typical miniaturised two-boom hydraulic jumbo capable of operating remotely from its powerpack.

Figure 8 **A miniaturised two-boom hydraulic jumbo operating remotely from an electro-hydraulic powerpack**

The transport function of the carrier would be taken up by the monorail, requiring the provision of a simple drill carriage to enable the unit to approach the working face. Power to operate the drills and associated equipment would come from an electro-hydraulic power pack which would remain attached to the monorail and draw electricity from it. This arrangement can be based entirely on existing components which may be readily adapted to suit.

Occasions have arisen where geotechnical assessment has identified the need for a non-rectilinear excavation layout as a design response to high and/or anomalous stress regimes. Implementation of such designs has been rendered very difficult because of the inability of LHDs, (or 'boggers') to satisfactorily clear broken rock from the consequent 'awkward' shape, resulting in the use of humans wielding shovels to do the job. Conveyor type loading machines fitted with 'backhoe' digging arms have been successfully employed to do this work. The arm, in addition to the digging bucket, can be equipped with a hydraulic breaker to carry out scaling, and a shotcreting lance can be fitted should that be required. The shape of the bucket on these machines is such that it can remove material from awkward locations and be used as a scaling tool if required (Figure 9).

Figure 9 **A 'backhoe' conveyor type loading machine**

From a loading point of view this type of machine is an extremely productive device, the smallest model of which is designed to load at a rate of 2 m^3/min. It's conveying rate, (which is dependent on the size of the broken material), can be three times this. Its use eliminates the need for turning bays as it can load directly into a hopper or tub of a monorail. A monorail train can push its 'hoppers' or 'tubs' to where they can be filled by the loader. A hopper shunting device, similar to the classic 'cherry picker' or car transit, except based on the suspended arrangement of the monorail, might be necessary to permit the exchange of full hoppers for empty ones. Such devices do exist and are simpler than the original rail based equipment. A simpler solution can be to use an 'over-the-top' system of exchanging tubs using the monorail lifting system. The backacter assembly, as supplied by one manufacturer, is readily interchangeable with the more familiar ‘paddle’ type of mucking system marketed by that enterprise (Figure 10).

Figure 10 A small rail mounted conveyor type loader fitted with ’paddle’ mucking arms

The smallest version of this machine is currently a rail mounted unit, but the manufacturer advises that this can be made available with alternative undercarriages such as crawler tracks. The loader would travel to the working face on a transport beam supported on the monorail. When needed for use it would be lowered to the ground, moving forward to the muckpile, drawing its power from the monorail via umbilical cable and sliding current collector.

Desk Top comparison of a conventional diesel/rubber tyred mining system with one based on SMT Scharf monorail technology. It must be noted that the actual development work for the monorail would be carried out using trackless equipment.

7 Drive dimensions

Opening sizes of 3 m width by 3.0 m height have been suggested for one train and for two trains 3.8 m width by 3.0 m height.

Typical configurations are shown in Figures 11 for one train and Figures 12 for two trains.

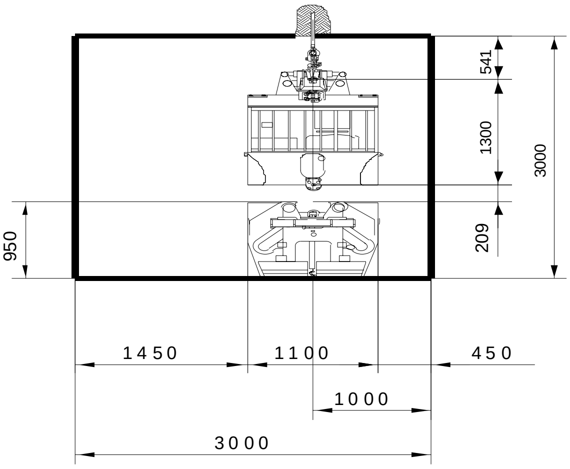

Figure 11 Cross Section of Opening Size Required One Train (Scharf)

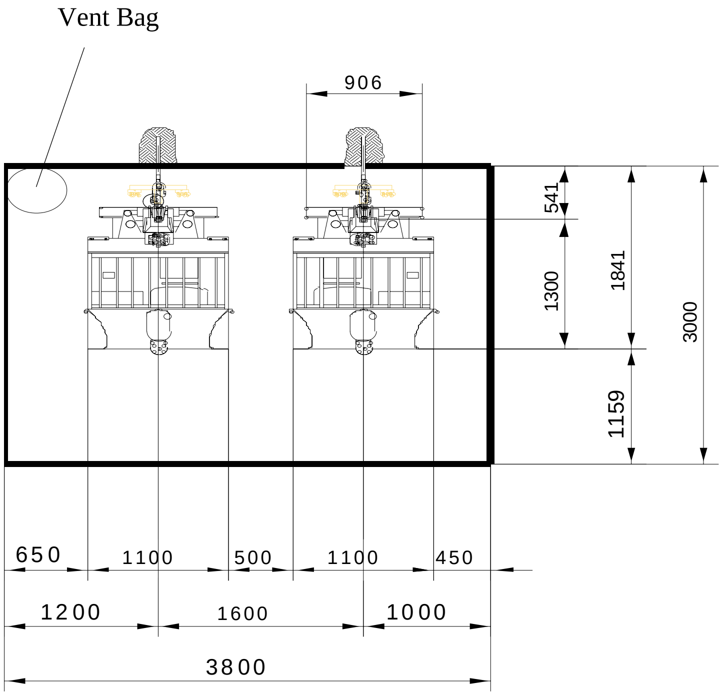

Figure 12 Cross Section of Opening Size Required For Two Trains (Scharf)

The ventilation bag shown in Figure 12 is located adjacent to the monorail and is less than 650 mm. The ventilation bag diameter therefore adds to the opening width. Temporary ventilation requirements for decline development typically calls for two 1400 mm bags to enable blast fumes to be exhausted within a reasonable time to enable the development cycle to continue. Typically evacuation times of 30 minutes are called for but are often not achieved at greater depths. Allowing 200 mm clearance between the monorail and vent bag would require a width of 4750 mm. With a height of 3 metres a clearance between the bottom vent bag and the floor would be 200 mm. Installing the ventilation bags on the floor under the monorail to save width is not considered a practical option as it prevents access other than via the monorails, the vent bag cannot be installed close to the face and the vent bag may be damaged by any object falling from the monorail. Figure 11 shows a single train has 1450 mm available for a vent bag and required clearance from monorail.

Loading a 950 mm high container with a G 211 side tip loader would require a minimum opening height of 3025 mm to prevent the loader bucket hitting the backs of the opening. Allowing a clearance of 200 mm would require a minimum height of 3225 mm.

The slow speed of the G 211 side tip loader would require the use of a rubber-tyred LHD for at least bogging development material from the ore drive development and blasted ore from the stope to a stockpile on the level. The width of the LHD and jumbo drill must therefore be considered in calculating the opening size. If the equipment is to be driven in and out of the mine for maintenance the Mine Safety and Inspection Regulations 1995, Regulation 10.39 (2) (a) and (b) apply, therefore requiring a total horizontal clearance of not less than 1.8 m based on the widest vehicle used in the mine and a total vertical clearance of not less than 600 mm based on the highest vehicle used in the mine. Exemptions from this regulation can be given by the State Mining Engineer but are treated on an individual case basis.

Alternatively the equipment may be transported by the monorail however the current model produced by Scharf is limited to 25 t for a single payload. The Elphinstone R1300G is the only LHD weighing less than 25 t. The bucket of the LHD may be removed and refitted underground reducing the width. Transporting the R1300G by monorail would require a minimum width 950 mm without clearance. The clearance between the R1300G and the sides of the opening with two monorails would be 50 mm. With a more realistic clearance of 200 mm the required dimensions would be 3950 mm excluding the vent bag. Using two 1400 mm diameter vent bags and a clearance of 200 mm between the vent bag and monorail would require an additional 950 mm making an opening width of 4950 mm. Based on the jumbo drill an additional 105 mm is required without clearance. The dimension required after allowing a 200 mm clearance between the jumbo drill and opening wall and a 1400 mm vent bag and a clearance between the vent bag and monorail of 200 mm would be 5055 mm.

The space required for the carrying beam is 1100 mm below the backs. Adding a height of 2265 mm for the highest vehicle the jumbo drill requires a height of 3365 mm without allowing any clearance. Adding a clearance of 200 mm requires a vertical opening of 3565 mm.

Therefore the minimum opening size required for a decline development using two monorail rails with temporary ventilation and accommodating the transport of a Rocket Boomer M2D jumbo drill and an Elphinstone R1300G LHD by monorail is 5.1 m wide by 3.6 m high. Where permanent ventilation is installed a vent bag diameter of 1.0 metres would be typical therefore the opening width could be reduced to 4.7 m.

8 Monorail installation

The EMTS runs on an "I" beam rail suspended from the roof by chains attached to suspension bolts. The Hilti OneStep anchor bolt is used as the suspension bolt. Each bolt costs A$ 107 and requires the purchase of a dispenser A$ 15,000 each and intensifier A$ 12,000 for the installation. The bolt has a diameter of 38.5 mm a length of 2.5 metres and requires a 41 mm diameter hole. The hole is drilled to a depth of 2 metres and can be drilled with a jumbo. Resin is contained within the bolt. Bolt installation requires one operator and can be installed in 40 seconds after the hole is drilled. The cost of the conductor bar, rail, suspension of rail and all connecting pieces excluding electrical distribution board was estimated by Scharf to be 275 Euro per metre (A$ 462). Scharf estimate a crew of 5 personnel can install 50 to 60 m per 10 hour shift. Four fully enclosed conductor bars provide power to the monorail.

9 Evaluation of monorail application for a narrow vein deposit

Access to the mine is via a 63 metre vertical box cut followed by 1800 m of straight decline at a gradient of 1 in 6.4 (280 m vertical depth) taken off the bottom of the box cut then 2500 m of spiral decline at a gradient of 1 in 7 (360 m). The straight decline targets the top of the orebody. The box cut is accessed by 440 metres of a 1 in 7 ramp. A production rate of 250000 t of ore per annum is required or 528 t of ore per shift.

An opening size of 5.0 m width by 5.8 m height was selected for the straight section where temporary ventilation was installed using convention truck haulage. A 5.0 m wide by 5.3 m height opening was selected for the straight section after permanent ventilation was installed and the spiral section. An opening size of 5.1 m width by 3.6 m height was selected for the twin rail monorail system where permanent ventilation was not installed. Where permanent ventilation was installed an opening size of 4.7 m width by 3.6 m height was used.

Temporary ventilation for decline development required two 1400 mm vent bags. Air requirements were determined by the maximum time allowed to expel blast fume and allow a working environment conforming to the Mine Safety and Inspection Regulations rather than air requirements for equipment. Where permanent ventilation was installed the vent bag size was reduced to one metre diameter.

The cycle times and pay loads were compared using a two rail monorail system and Hitachi AH 400D trucks loaded with a Elphinstone R1700G LHD. The number of trucks required for the development of the decline was two to a vertical depth of 377 m and three trucks thereafter. The payload carried per truck was 32.4 t achieved with three loader passes. Each monorail train required 6 containers to achieve a payload of 31.6 t and required two loader passes per container.

The conventional decline development cycle was bogging the muckpile and transporting the waste to a stockpile on the level above. When the muckpile was removed from the face drilling of the face commenced and waste was bogged from the stockpile into trucks. The decline development cycle for the monorail was bogging and transporting the ore from the face and dumping directly into the containers. Stockpiles were not required. When the container is full it is lifted up by the lifting beam.

The cycle time to bog and transport the muckpile material from one 3.7 m cut to the stockpile ranged from 1.3 hours to 2.2 hours and 1.2 hours to 3.8 hours for the load and haul cycle. The bog, load and haul cycle using two monorail trains ranged from 2.1 hours to 3.6 hours. The time to load one truck ranged from 3.6 minutes to 6 minutes compared to 33 minutes to load the six monorail containers based on the monorail train being located 20 metres away from the face. Loading efficiency would be improved if a rubber tyred side tip loader could be purchased for use when developing conventional gradient declines. The monorail train speed in the 1 in 6.4 (9^o) gradient straight section is estimated at 1.65 m /s or 5.9 kmph compared with 6.6 kmph for a Hitachi AD 400 D truck. In the 1 in 7 (8^o) gradient spiral section the monorail speed is estimated at 1.8 m/s or 6.5 kmph compared to 6.8 kmph with the Hitachi AD 400 D truck.

Level development using conventional truck haulage assumed development waste from the level being developed was carted to a stockpile on the level above for loading into trucks. Level development with the monorail assumed development waste to be bogged and transported to the monorail train located in the decline 5 m up the decline from the cross decline intersection. The monorail train can not be taken onto the level until the level is developed. The time to bog one 3.7 m cut of cross cut to the stockpile using convention truck and LHD ranged from 1.6 hour to 3 hours and 1 hour to 2.4 hours for load and haul cycle. The bog, load and haul cycle for the monorail train system ranged from 2.4 to 4 hours.

Development of ore drives and stope ore handling assumed the ore was bogged from the ore drive or stope with an Elphinstone R1300G LHD to a stockpile located 20 metres from the ore drive exit. The monorail trains were assumed to travel along the cross cut to a distance of 5 metres from the stockpile exit. The G 211 side tip loader was then used to transport the ore from the stockpile to the monorail containers. Each monorail train was assumed to have six containers each containing 7 t of ore each.

To achieve an ore production rate of 250000 t per annum requires the operation of 3 to 4 monorail trains each with a payload of 42 t compared to 3 to 4 trucks each containing 37 t. The loading of the containers requires 27 minutes compared to 4 to 6.5 minutes using the R1700G LHD and Hitachi AH40 D trucks.

10 Costs

Capital and operating cost estimates are based on a monorail train consisting of two driver cabins, four drive units and six lifting beams with a payload of 36 t, excluding the weight of containers. The installed power on the train is 232 kW. A train with such a configuration was quoted by Scharf to cost 1,000,000 euro delivered to a German port and excluding containers to hold material. Scharf estimate shipping would require two 40 foot containers and weigh a total of 14 t. Drawings for the containers to hold material have been sent to CPC Engineering Kambalda for quotation.

Installation of the rail requires the purchase of a shunting trolley and the installation of the bolts to attach the rail to the backs of the opening requires specialised equipment. Capital equipment details are shown in Table 1. The cost of rail, electrical components, bolts and labour to install the monorail was estimated at $A520 per metre excluding the cost of suspension components. The operating cost of the train was estimated at $A91.70/operating hour.

Table 1 Capital costs of equipment

Component	Euro	A$	Remark
Train	1000000	1680000	Price by Scharf
Containers			Awaiting price CPC
Monorail Tools	6000	10080	Price by Scharf
Shunting Trolley	30000	50400	Price by Scharf
Dispenser (Bolt Installation)		15000	Price by Hilti
Intensifier (Bolt Installation)		12000	Price by Hilti
Total		**1767480**	

Scharf estimated that 50-60 metres of rail could be installed per shift using a crew of five plus a shunt trolley, jumbo drill and operator. Estimation of operating costs is shown in Table 2. Where the train is required to be run onto levels or run into a bypass drive, a pneumatically operated switch will be required. Substations are required every 800 m of rail. A single train with 232 kW of installed power would require a transformer with a minimum capacity 167 kVA every 800 m. In this case a standard 200 kVA transformer would be selected.

Table 2 Operating cost of train

Component	Euro / Operating Hour	$A / Operating Hour
Parts	7.14	12.00
Power		34.40
Operating Labour		42.71
Maintenance Labour		2.59
Total		**91.70**

The hourly operating cost of a monorail train with a 36 t payload (excluding weight of containers) is the same as the hourly operating cost for a 37 t payload Hitachi AH400-D underground truck. Detail of the comparison is shown in Table 8. In the eastern part of Australia where the cost to generate power is approximately 50% of the cost to generate power at a remote Western Australia minesite the operating cost of the monorail rail train would be reduced to A$ 31 per operating hour, a saving of A$ 18 per operating hour over the Hitachi truck. Figure 13 shows the relationship between power cost and monorail operating cost.

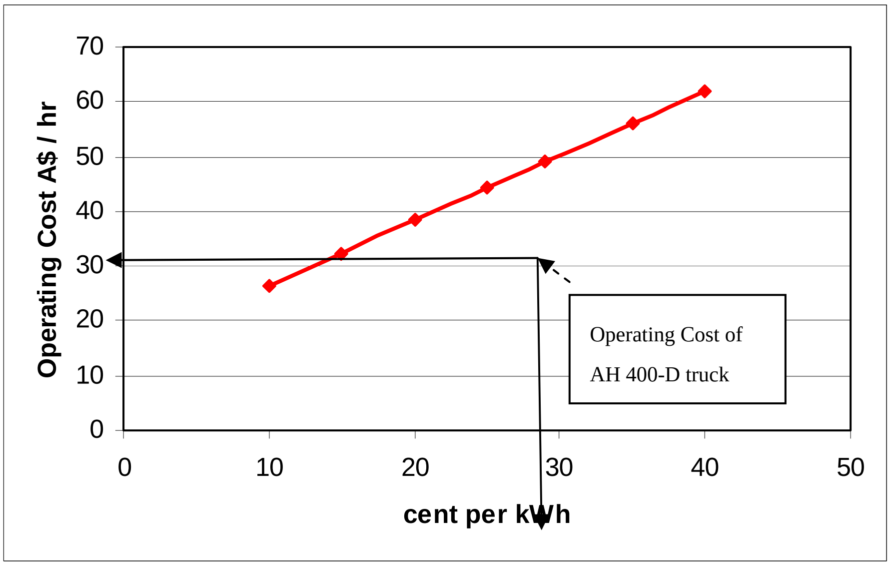

Figure 13 Effect of power cost on monorail operating cost

11 Continuous monorail

The concept of a continuous monorail system was investigated as a means to reduce the monorail cycle time and reduce the need for stockpiles. The concept requires an independent drilling unit with its own power supply attached to the monorail. A hydraulic suction unit fitted under the monorail train cabin could load the blasted material into containers. The concept would allow part of the face to be drilled and blasted then loaded into the monorail containers using the hydraulic unit. When the containers are full the drill can continue to drill the face whilst waiting for the monorail train to return. The concept is illustrated in Figure 14.

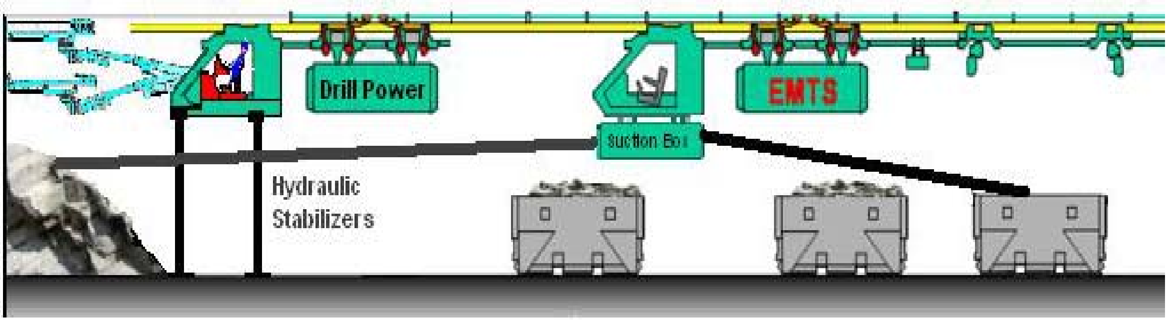

Figure 14 Concept of a continuous monorail system

The proportion of face drilled and blasted before hauling will require a balance of drilling and blasting cycle time and the load and haul cycle time. Using a hydraulic suction unit would require the rock to be blasted to a maximum size of 200 mm. Blasting techniques to achieve such fragmentation require investigating. Research on the design of integrated drill-blast-load-haul system is on-going.

A 3.0 m wide by 3.0 m high by 3.7 m long cut produces a muck pile of 33.3 BCM of material or 93.2 t at an SG of 2.8. It would take 1.18 hours to drill the face using a twin boom jumbo based on an instantaneous drilling rate of 75 metres per hour, 0.65 hours to charge the face and 1.9 hours for other activities associated with the blast. Details of other activities associated with the blast are shown in Table 3. In good quality ground surface ground support such as mesh is only required by statutory regulations in Western Australia where the height of face exceeds 3.5 metres, therefore no time to install ground support has been allowed for. The time to load and haul the cut using the monorail would be 2 hours for a distance of 2 kilometres based on three monorail loads of 31.1 t each.

Table 3 Estimated time required for other activities associated with blasting

Activity	Time (Hours)
Mark up face	0.25
Tie in blast	0.25
Evacuate blast area	0.08
Evacuate blast fumes	0.5
Water down muckpile	0.2
Check walls and backs	0.2
Scale down	0.25
Ground Support	0
Inspect butts	0.2
Total	**1.93**

12 Automation and communication

The electrical conductors fitted to the monorail form a continuous network which can be used to carry high quality communication. This is currently used for various purposes including traffic management in situations where more than one machine is operating. Given that the transport equipment is ‘captive’ on the rail; there is a clear opportunity for implementing unmanned operation. Similarly, tele-remote operation of the drilling and mucking functions are possible.

13 Conclusions

Electro-monorail haulage is a viable alternative operating system for deep underground mining. The system can be used as a second level electrical reticulation system. Other benefits include elimination of diesel powered equipment in the underground environment, lower ground support and haulage costs and potential for rapid decline development.

A decline developed by two-train monorail systems requires an opening size of 5.1 m width by 3.6 m height where temporary ventilation is used. The opening size may be reduced to 4.7 m width by 3.6 m height where permanent ventilation is installed. Opening size is based on equipment being transported into the mine by the monorail.

The capital cost of the monorail is significantly higher than for a similar payload truck. The operating cost of the monorail at a remote Western Australian minesite using diesel power generation is estimated to be the same as a similar payload underground truck (A$ 49 per operating hour). Rail components and installation is estimated at A$ 520 per metre.

Operating cost of the monorail would be significantly less than a similar payload truck if the cost of power was significantly reduced to levels occurring in the eastern part of Australia.

A concept of using a continuous monorail system has been suggested as a method of making the monorail cycle time more comparable with conventional LHD and truck techniques whilst eliminating the need for stockpiles.

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