THE CURRENT STATE AND FUTURE REQUIREMENTS OF CONTINUOUS HAULAGE SYSTEMS FOR UNDERGROUND GATEROAD DEVELOPMENT

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ABSTRACT

Since the 1980's in Australia, there have been numerous attempts to introduce some form of continuous haulage system into underground coal mines. However, little has changed, with shuttle cars still the primary method of coal clearance from the face to the panel conveyor in bord and pillar operations and also longwall gateroad development.

The cross-sectional area of these existing batch coal haulage systems is large in comparison to the cross-sectional area of the roadway. This makes the supply of material to the face a batch process, where the shuttle cars must temporarily move to allow re-stocking of items such as roof bolts, chemicals and mesh.

There is currently a push to achieve 10 MPOH (metres per operating hour) on a continuous basis for 20 hours per day in Australia. Such rates have been achieved in very small bursts, but cannot be sustained.

At the request of the Australian Coal Association Research Program (ACARP), a project was established: *10 MPOH Continuous Haulage System For Longwall Gateroad Development* (Wypych, 2012) to identify any continuous haulage systems currently available and any related technologies capable of meeting the requirements, or those under development which could be implemented for underground use.

This paper will provide a background to the current "best practice" with respect to coal clearance in underground coal mines in Australia; include a summary of the vital elements seen as being required for a successful continuous haulage system; and present a review of the most promising candidates for the creation of a successful continuous haulage system, including their strengths and weaknesses.

1. INTRODUCTION

The Australian Coal Association Research Program (ACARP) funds coal mining research in Australia, and with the ever increasing focus on worker safety, productivity and efficiency, there has been a renewed push to develop an underground continuous haulage system for underground mines in Australia. There have been several attempts to do this, dating back to the 1980s. However, for various reasons nothing has yet come to fruition.

ACARP has a Roadway Development Task Group (RDTG), under which the CM2010 Roadway Development Improvement Strategy was conceived in 2008 as a means of targeting research towards the development of a safe, high capacity gateroad development system capable of 10 MPOH (metres per operating hour), 20 hours per day. With the current systems being used, this rate can only be achieved in short bursts, if at all.

Four key enabling technologies were identified as critical to the development of such a system, while three organisational competencies were considered essential to underpinning those technologies and sustaining the productive capacity of the development system, as shown in Table 1.

Key Enabling Technologies	**Remotely Supervised Continuous Miner**	**Automated Installation of Roof and Rib Supports**	**Continuous Haulage**	**Integrated Face and Panel Services**
Organisational Competencies	**Improved Engineering Availability**			
	People Behaviour and Skills			
	Planning, Organisation and Process Control			

Table 1. Key Elements - CM2010 Roadway Development Improvement Strategy

Roadway development-related research and development initially focussed on the first two enabling technologies, with three major projects supported:

- C18023 Self Steering Continuous Miner
- C17018 Automated Bolt and Mesh Installation
- C17004 Alternative, Polymeric Skin Confinement System – ToughSkin

ACARP subsequently supported projects focussed on the fourth of these enabling technologies, which were aimed at integrating face and panel services:

- C20034 Rapid Advance Conveyor
- C20035 Self Advancing Monorail

This left the third key enabling technology, Continuous Haulage, to be investigated and from the roadway development R&D, four main issues were identified as a result of the findings from the other projects already underway:

- Only limited on-board storage of materials would be possible on current continuous miner configurations fitted with the automated bolt and mesh handling systems under development, unless minimum cutting heights could be increased to 3.2 m or more (noting that on-board storage is particularly constrained by adoption of high rate, elevating discharge systems through the centre of the miner). Limited on-board storage necessitates regular replenishment of strata support materials, an activity that is expected to further conflict with coal haulage operations as development rates improve.
- Development rates achieved at a 'best practice' mine (with low support density) typically range from 3 to 8 MPOH (average 5 MPOH) as the roadways advance through the pillar cycle, with the development process rapidly becoming haulage constrained 60 m or so from the conveyor boot end. This suggests that the target

10 MPOH development rate is unsustainable with batch haulage systems, despite the increase in cutting rates and haulage payloads.

- As shown in Figure 1, shuttle cars utilise up to 70% of the roadway profile when loaded, effectively isolating the roadway from other activities at high advance rates (noting that 10 MPOH is equivalent to 40 shuttle car movements per hour, or one every 90 seconds). Therefore, coal clearance and strata support material logistics systems need to work in parallel to realise targeted development rates.

- While 10 MPOH may be considered visionary, it is equivalent to a continuous rating of 4–5 tonnes per minute, well below the designed cutting rates of current generation continuous miners (>30 tpm). While a high cut rate may be a necessity with a batch haulage system, adoption of a continuous haulage system may allow a lower, continuously rated mining machine to be employed, one which is purpose designed, such as for gateroad development with high support densities. In turn, this might similarly allow a small cross-section, continuously rated continuous haulage system to be employed (say a minimum of 5 tpm to a maximum of 10 tpm), one which is more compatible with the strata support materials logistics function.

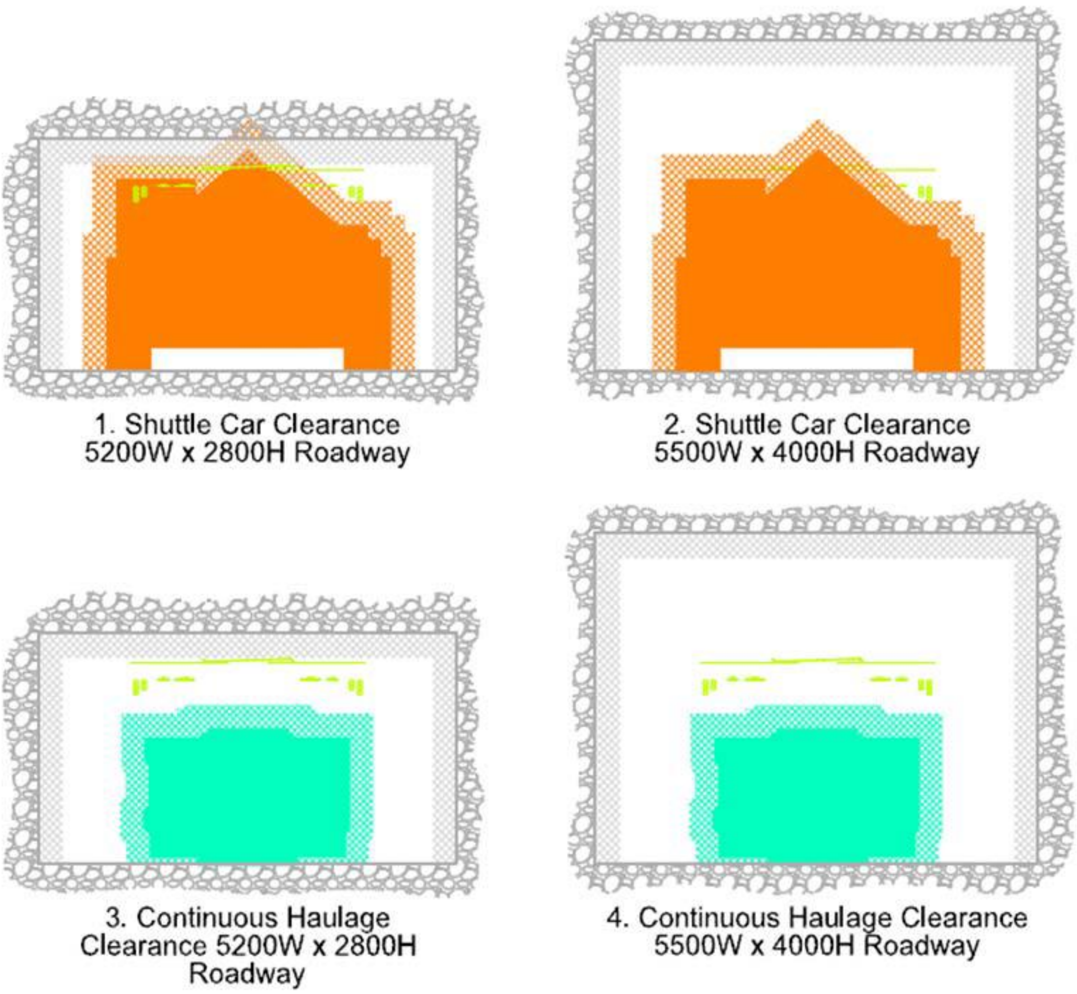

Figure 1. The profile of current batch and continuous haulage systems

(Wypych, 2012)

As a result of the four main points above, the RDTG requested that a project focussed on continuous haulage be developed with the objectives of:

- Assessing existing continuous haulage systems, technologies and concepts that could be utilised as the basis of a small profile, low capacity coal clearance system.
- Meeting the CM2010 objectives of 10 MPOH 20 hours per day.
- Able to be integrated with other elements of the roadway development system to provide a safe, efficient, sustainable and high capacity roadway development system.

2. RESEARCH STRATEGY

A research team was formed consisting of three University of Wollongong staff and five industry representatives with vast experience in all aspects of underground mining. The project was to have a six month maximum time frame for completion. The strategy adopted by the team comprised the following three key phases:

- Familiarisation and data gathering via site visits, meetings with mine staff and original equipment manufacturers (OEMs), intellectual property (IP) and regulatory reviews, and extensive literature reviews.
- Evaluation and short-listing of technologies and systems.
- A second round of technology evaluations.

2.1 FAMILIARISATION AND DATA GATHERING PHASE

The familiarisation and data gathering phase included:

- Mine visits and inspections of currently operating continuous haulage systems at two Australian underground coal mines.
- Site visits and meetings with mining industry OEMs to evaluate developments in continuous haulage and conveying systems and associated technologies.
- Site visits to industrial facilities and OEMs from other industry sectors to evaluate the potential application of these technologies to continuous haulage.
- Presentations from, and discussions with, other key researchers involved in the R&D of roadway development-related enabling technologies to understand the issues associated with integrating the potential technologies into a high capacity roadway development system.
- Engagement of specialist intellectual property lawyers to undertake an international review of IP databases and identify relevant patents.
- Detailing and reviewing key aspects of mine regulations, standards and guidelines pertaining to continuous haulage systems and their associated technologies.
- Extensive literature review of continuous haulage systems and any technologies within the scope of the project deemed potentially suitable for inclusion.

A comprehensive listing of all relevant regulations, standards, and guidelines can be found in the final report released to ACARP (accessible via the ACARP website). The project team are of the opinion that these regulatory requirements are generally well understood by OEMs and the industry and should not prove to be an obstacle to the development of a 10 MPOH rated continuous haulage system for longwall gateroad development. Regulations, standards, and guidelines which are expected to require particular consideration include:

- fire resistance anti-static (FRAS) belting
- personal proximity due to automated operating functions
- compliance with risk management, programmable electronic systems and safety integrity limit requirements
- safety of machinery, including guarding
- compliance to the conveyor standards
- crane code (relevant for monorail suspended systems).

A detailed technology review was undertaken. Technologies currently used and those which could be adapted for use in continuous haulage in underground coal mines were identified:

- Mobile Bridge Conveyors (Long Airdox/Caterpillar, Joy, Stamler, Jeffery, Fairchild)
- DMS/Prairie Development Flexiveyor (multi-car/bridge conveyor system)
- Klöckner-Becorit Crawler-Veyor (Consol TramVeyor, A L Lee Corp Crawler-Veyor, Archveyor)
- Hilgefort Flexihaul self driven conveyor
- Joy 2FCT
- Joy 4FCT
- Sandvik VACHS 500
- Premron E-BS (Enerka-Becker System) closed conveyor system
- Innovative Conveying Systems International (ICS)
- Sigma monorail mounted conveyor system
- Bosmin Coaxial Pipe (CAP) conveyor
- Pathwinder conveyor
- pipe or tube belt conveyor systems
- pneumatic conveying systems
- slurry transportation systems

The project team then reviewed all the data based on the available facts to develop what they considered the key functional specifications needed in order to produce a viable continuous haulage system.

2.2 FUNCTIONAL SPECIFICATION

The key functionality of a 10 MPOH gateroad development continuous haulage system was reviewed and it was agreed by the project members to adhere to the following must haves and should haves:

The system MUST:

1. Have a minimum continuous rating capacity of 4–5 tonnes per minute and an operating continuous rating of between 5–10 tonnes per minute at a bulk density of 900 kg/m^3.
2. Be able to readily and easily track behind the continuous miner and continuously receive mined product throughout all stages of the two or three entry roadway development process, in typical seam conditions including 5.2 m-wide roadways, ±1:8 gradients (both pitch and roll), and soft (4 MPa) and wet floor conditions.
3. Be capable of handling run-of-mine coal product and other strata typically found in and adjacent to the coal seam.
4. Be capable of continuously conveying run-of-mine product at a specified maximum size (to be determined).
5. Be capable of conveying product at its rated capacity continuously from the face to the panel conveyor over a distance of 200 m, through a range of two sixty to ninety degree opposing corners (cut-through) and continuously discharging product onto the panel conveyor.
6. Have a profile that allows the face to be supplied with strata support and other materials at a sustained rate equivalent to 10 MPOH (e.g. profile to be less than 45% of a roadway cross-section of 5.2 m-wide and 2.8 m-high).
7. Incorporate proximity detection and collision avoidance systems to guard against machine-machine, machine-person and machine-roadway/infrastructure collisions.
8. Not expose personnel to unplanned movements or other uncontrolled hazards.
9. Meet all relevant regulatory standards and IP requirements.

The system SHOULD:

1. Be able to integrate into an automated roadway development system which includes a self-steered or remotely steered continuous miner, automated strata support handling and installation systems, and self-advancing face services (e.g. power, water, pump-out, communications).
2. Require minimum manual labour to install, operate or relocate the system.
3. Consistently maintain its track (±50 mm) as it advances and retreats through the development cycle.
4. Be able to readily and rapidly retreat from the face and relocate to an adjacent roadway or panel.
5. Require no additional excavation or support to enable the system to operate adjacent to, and to discharge onto, the panel conveyor.
6. Require a minimum of additional infrastructure to advance and retreat the system and to allow the system to discharge onto the panel conveyor.

7. Be capable of handling run-of-mine saturated coal slurries as generated in mines.
8. Have minimal spillage or carry-back of fines or product.
9. Have demonstrated a high system reliability and availability.
10. Have no high wear components, and have an acceptable maintenance regime and costs.
11. Enable mine service's infrastructure such as power, water, pump-out and compressed air to be installed in the roadway whilst the system is operating in that roadway.

A technology matrix was subsequently developed, where each technology was initially ranked against the nine "MUST haves", utilising a three tier system which presented an overview of the technologies with the highest chance of being adapted for continuous haulage applications.

Following the culling of a number of non-suitable technologies (e.g. pneumatic and hydraulic/slurry transportation systems), the remaining technologies were subjected to a detailed Strength, Weakness, Opportunity, Threat (SWOT) analysis to further fully evaluate their potential application in a 10 MPOH gateroad development continuous haulage system. As part of this process, the major risks associated with application of the various technologies underground were also identified as were any information shortfalls relating to specific technologies.

2.3 OVERVIEW OF CONTINUOUS HAULAGE TECHNOLOGIES

This three phase research strategy allowed all the continuous haulage technologies to be evaluated against the functional specification through a multi-phase assessment process, including the technology review, technology matrix and SWOT analyses. This process resulted in five of the technologies being short-listed for a second round of evaluations, including the four single length closed conveying systems and the multiple car/bridge conveyor system listed below and detailed in the following sections.

- Bosmin Coaxial Pipe (CAP) Conveyor
- Innovative Conveying Systems International (ICS)
- Premron E-BS (Enerka-Becker System) Closed Conveyor System
- Sandvik VACHS 500
- DMS/Prairie Development Flexiveyor (multi-car/bridge conveyor system)

Each of the five short-listed OEMs was provided with a copy of the relevant interim findings and conclusions from the technology matrix and SWOT analysis, and invited to meet with the project team to review those findings and propose strategies to address any identified deficiencies. Following these presentations, the study team compiled the following key observations with respect to the short-listed technologies.

2.3.1 Bosmin Coaxial Pipe (CAP) Conveyor

Overview

- The Bosmin Coaxial Pipe Conveyor is a development on the conventional pipe or tube belt conveyor which, as the name implies, incorporates the delivery and return conveyors into a single bi-directional pipe by utilising flexible helical idler springs to support and contain the two belt sections, as shown in Figure 2.
- At the loading point, the CAP conveyor opens flat allowing the belt to be loaded and discharged in a similar manner to a conventional troughed belt. However, once the belt is loaded, the belt progressively wraps into a pipe formation to enable material to be conveyed along a curved pathway. The return belt is also wrapped into a pipe shape, but is positioned outside the delivery belt. The two belts are separated by an internal idler set with a belt running on either side of the idler. The belt again opens out and flattens at the discharge point like a conventional conveyor.

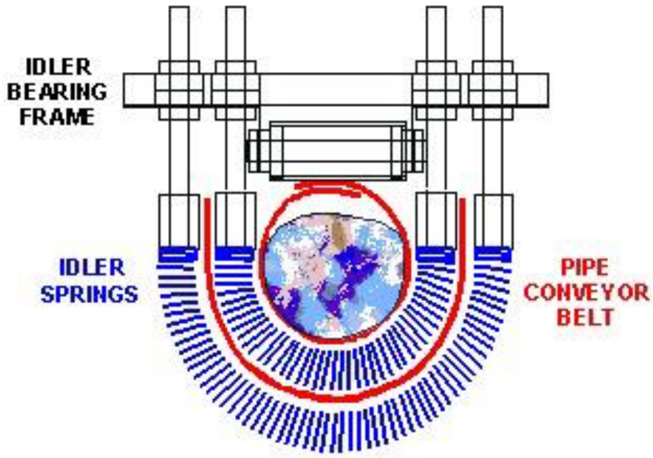

Figure 2. Configuration of Bosmin Co-axial Pipe Conveyor

(Bosmin, N.D)

- The concept system was initially developed as an alternative to hauling material from open cut mines by truck, and also has the potential to be applied in underground mining applications.
- A series of laboratory scale models were developed (for example Figure 3) to demonstrate and validate the design principles of the system, including both fixed plant and flexible mobile conveyor models. Individual components such as the flexible helical idler springs were also subjected to extensive testing to confirm their extensive life rating.
- It appears that the CAP conveyor can negotiate curves down to 25:1 curve radius/pipe diameter, has a relatively light conveyor structure and belting, low full load running resistance and short transition distances between the flattened and pipe sections.

- Bosmin calculated that a 300 mm diameter CAP conveyor would have a capacity of 579 m^3/hr (520 tph) at a belt speed of 3 m/s.
- They have been working closely with an OEM to develop a self-advancing monorail system to carry the CAP conveyor for gateroad development.

Figure 3. Working laboratory scale-model of Bosmin Co-axial Pipe Conveyor

(Bosmin, N.D.)

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- It is the least mature of the technologies identified and would require substantial research, development and testing to both upscale the system and to validate the underlying design principles.
- Due to its co-axial design, it offers the smallest profile of all the systems identified, hence, would minimise the potential conflict between the coal clearance, the materials re-supply and the face services functions.
- The system utilises horizontally mounted, flat and low profile tail (loading) and head (discharge) pulleys, which are similarly expected to minimise potential conflicts between the coal clearance, the materials re-supply and the face services functions.
- Like all closed conveyor systems, this conveyor requires ROM product to be sized and the flow rate to be controlled to prevent blockages, hence the need for a surge/sizer car to be utilised behind the miner, which has the potential to cause conflicts.
- Bosmin have not progressed detailed design beyond the current workshop-scale coal clearance demonstration model and would benefit from additional industry support to further its development.

2.3.2 Innovative Conveying Systems International (ICS)

Overview

- The ICS is a closed conveyor system, (Figure 4), which has found application in fixed plant installations in Australia due to its extremely small turning radius, ability to convey up steep gradients and through complex horizontal/vertical curves and its closed construction.
- When viewed in cross-section, the ICS forms a shape similar to an elliptical pipe or pear. The belt consists of two components which are mechanically joined.
- The belt edges are termed 'J-sections' as they resemble an inverted J. These sections are multi-functional and are constructed as a composite. They contain the main tensile reinforcing members as well as metal ribs. The ribs stiffen the hoop strength of the J-section, enabling it to retain its shape while supported on the idlers, and carries the weight of the loaded belt. The J-sections also serve as a means to motivate the belt via caterpillar drive belts.

Figure 4. ICS system arrangement

(ICS, N.D.)

- The belt carcass is not subjected to tensile forces and is constructed with transverse corrugations along its entire length. These corrugations enable the belt to comply with extreme directional changes, (Figure 5). The corrugations also enhance the high angle capability of the belt.

(a)

(b)

Figure 5. (a) Belt forming closed tube (b) Discharge from flat belt

(ICS, N.D.)

- A feature of the unique belt design is that it allows the belt to be filled to a point just below the apex, equivalent to some 90% of its volumetric capacity.
- A modular frame suspends the belt, creates a path along which the conveyor and material travel, and provides the system with its required mobility. The frame can either be fixed in long stationary sections, or can be mounted on wheels in mobile applications. It is envisaged that a gateroad development system would be monorail mounted, or mounted on a dual rail suspension system, currently under development.
- The ICS is driven by a system of intermediate, caterpillar drive units, with variable speed drives being interfaced through a PLC.
- It will require a crusher car to be located behind the continuous miner.
- The ICS will also require a vertically mounted tail pulley and a horizontally mounted head (discharge) pulley – two vertically mounted pulleys may be considered with a side discharge if required.

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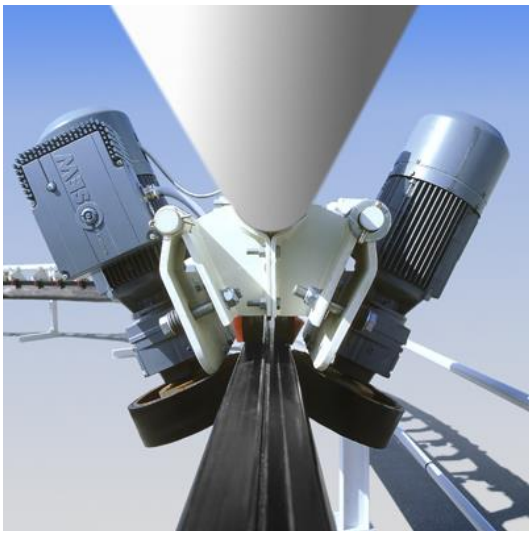
- The ICS conveying system was believed to be the only closed conveyor design that was actually operating in accordance with its underlying design principles, with the corrugated belting designed to stretch and contract as the belt negotiated tight corners.
- The J-hanger suspension system was clearly the most effective suspension of those studied, while the tractive effort required to motivate the belt was delivered via the suspension member and not through the belt fabric itself.
- Like the other closed conveyor systems, the ICS conveyor has a relatively large diameter, vertically mounted tail (loading) pulley and requires a surge hopper and sizer to regulate flow which, together with the loading station, could present challenges with the integration of the materials re-supply and face services functions.

- The belt is manufactured in 6 m lengths and is attached to the metal J-hanger assemblies and fastened together during installation. This allows damaged sections of belt to be quickly replaced in-situ (1.5 to 2 hours), while the fabric itself is amenable to being stitched together to affect a running repair. However, the effectiveness of both the belt jointing over time and the J-section hangers and their attachment to the belt fabric are unknowns at this stage.
- Both fixed plant and flexible, mobile wheel mounted systems have been developed and the technology is considered readily transferrable to a roof mounted application.
- Substantial development and design will be required to progress development of the ICS conveyor for underground coal application and to integrate other aspects of the gateroad development process, particularly the materials re-supply and services functions.

2.3.3 Premron E-BS (Enerka-Becker System) Closed Conveyor System

Overview

- The Enerka-Becker System (E-BS) is a closed conveyor system that has found widespread application in fixed plant installations throughout the world due to its extremely small turning radius, its ability to convey up steep gradients and through complex horizontal/vertical curves, and its closed construction (Figure 6).
- Using experience gained in above ground installations, Premron E-BS has continued to refine and upgrade the proposed system for longwall gateroad development. The system is expected to comprise a 1 400 mm wide E-BS conveyor suspended by idlers (800 mm centres) from a roof mounted monorail, with multiple, distributed 1.0–1.5 kW FLP conveyor drives controlled via a PLC to load share along its length. Some of the drives will be fitted with brakes to ensure a fast stoppage in an emergency and/or to prevent run-back. The drives will also communicate with the monorail propulsion system to ensure correct function on corners and bends. At this stage it is proposed to utilise a standard longwall/gateroad development monorail.
- The conveyor will require a crusher car located behind the continuous miner. It also will require a vertically mounted tail pulley and a horizontally mounted head (discharge) pulley.
- At 3 m/s, the maximum capacity appears to be around 450 m^3/hr, (400 tph).



(a) (b)

(d)

(c)

Figure 6. Premron E-BS Closed Conveyor System[4]

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- The Premron E-BS system is essentially a mature technology, however, the technology is unproven in a mobile, flexible application as contemplated for gateroad development.
- Technical reports obtained note that the underlying Enerka-Becker conveyor technology is well suited to a multiple distributed drive system with resulting low belt tensions, while the construction of the belt obviates the need to incorporate a steel wire rope tension member.
- The designers reported that at present, the 1 400 series conveyor is only capable of negotiating a minimum of 16 m radius curve, although they intended to explore how the radius could be reduced.
- The E-BS conveyor is mounted on a series of 6 metre-long monorail mounted bridges, with delivery and return idlers located in fixed positions along each of the

bridges. It was not clear whether these 6 metre-long bridges could, in fact, negotiate a curved monorail section which would be necessary when advancing into and through cut-throughs.

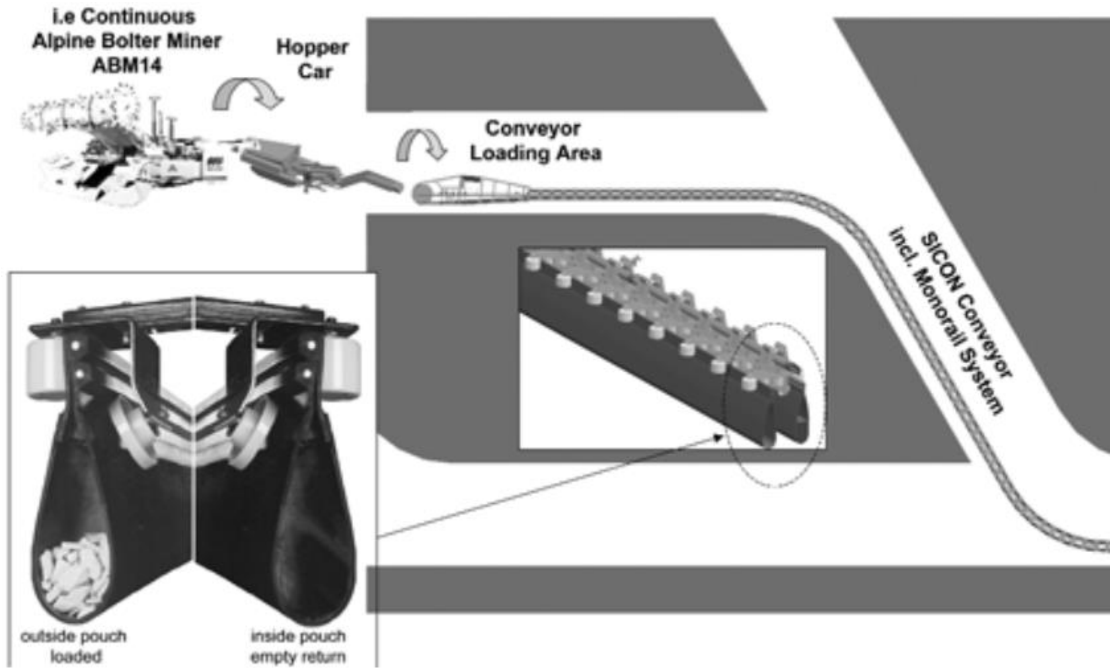
- The E-BS conveyor utilises a relatively large diameter, vertically mounted tail (loading) pulley and requires an extended loading station to separate and load the conveyor. Further, a similar diameter, horizontally mounted pulley is utilised at the head end in conjunction with an extended unloading and conveyor transitioning station. These relatively large pulley and loading/unloading configurations are expected to prove problematic with respect to their integration with the materials re-supply function (loading station) and gateroad conveyor and services (unloading station).
- An international supplier has been located for the FRAS belting, with the belting currently being subjected to FRAS testing with Australian testing authorities.
- Premron have an appreciation of the functions to be incorporated within an integrated roadway development system, however, like other smaller OEMs, they could benefit from industry support to flesh out the issues and challenges of this integration.

2.3.4 Sandvik VACHS 500

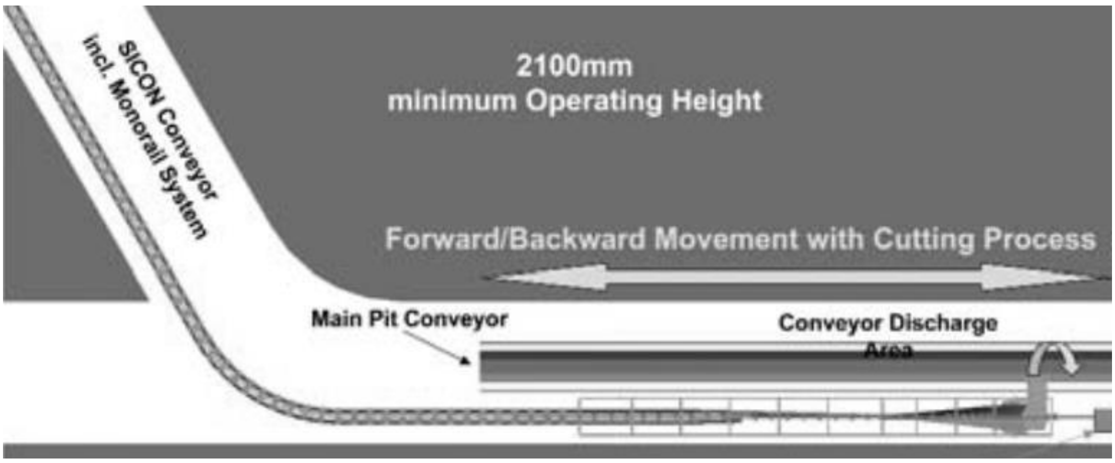
Overview

- The VACHS 500 consists of a monorail mounted SICON conveyor, a type of conveyor with a number of unique features.(Figure 7). Sandvik has built a prototype system in the USA and have trialled it in an above ground simulated roadway. Unfortunately, the industry partner withdrew support prior to the system being trialled underground, resulting in the suspension of the project until another industry partner can be identified.
- The SICON conveyor is a “closed” conveyor and is typically referred to as a bag or pouch conveyor, terminology which typifies its shape – referred to as a “teardrop” conveyor.
- The SICON conveyor uses a steel cable tension member in the rolled edge section of the conveyor which is separately vulcanised to the main body of the belt (which has no reinforcement).
- These conveyors are used extensively throughout the world in fixed plant installations, the main advantages being reported as their extremely small turning radius, ability to convey up steep gradients and through complex horizontal/vertical curves, and closed construction, which eliminates spillage and maximises security of valuable products (e.g. diamond bearing muck). The conveyors are typically end driven. There are reports of systems having multiple distributed drives to lower belt tensions, particularly where there are multiple fixed curves incorporated into the installation.
- The VACHS 500 system includes a mobile hopper car, (Figure 8) located immediately behind the continuous miner, the belt or haulage loading station, the monorail mounted SICON conveyor, and a belt or haulage unloading/transfer station. The design capacity of the proposed system is 500 tph.

- As part of their vision of an integrated gateroad development system, Sandvik also proposes suspending the auxiliary ventilation duct off the haulage monorail system, and to utilise the breaker car as a platform for installing both the monorail hanging bolts and secondary support, and for storage of strata support materials and monorail segments.
- It is evident that the system will require conveyor roadways of 3 m or more in height to enable the haulage unloading/transfer station to travel over the panel conveyor.



(a) Feed arrangement



(b) Discharge arrangement

Figure 7. Sandvik VACHS 500

(Sandvik, N.D.[1])

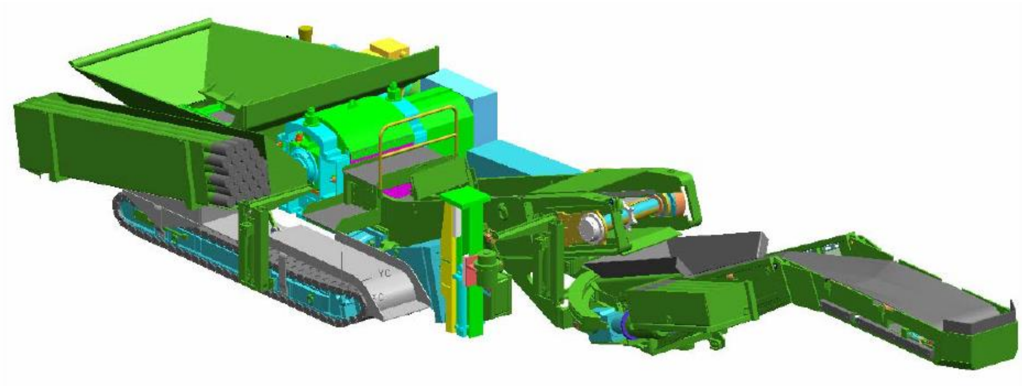


Figure 8 . Sandvik VACHS 500 hopper car

(Sandvik, N.D.[2])

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- Like the other closed conveyor systems studied, the VACHS 500 utilises a hopper/sizer to regulate coal flow and requires a relatively large diameter, vertically mounted tail pulley, loading station and transition section at the tail end immediately behind the continuous miner and beside the hopper/sizer. The design and configuration of the tail end/loading station/transition section/ hopper/sizer is critical with regard to potential conflicts with the materials re-supply and face services functions, and will similarly benefit from full 3D animation of the system to explore articulation of the tail pulley/loading station/transition section/hopper/sizer through the breakaway and cut-through.
- While it is recognised that there are some 150 SICON conveyors installed throughout the world, operators of the three systems inspected in Australia raised concerns regarding the fundamental design of the conveyor and its proneness to wear and damage, even in above ground, fixed plant installations.
- The issues raised by the research team regarding the inherent design of the SICON conveyor were noted by the designers, who advised that they would examine the issues separately and advise accordingly.
- It had been observed that a pendulum effect occurred when the belt was advanced or retreated, particularly in cut-throughs, although it is anticipated that this effect would be eliminated through adoption of multiple, distributed drives. Sandvik further advised that the multiple, distributed drive system was still under development.

2.3.5 DMS/Prairie Development Flexiveyor (multi-car/bridge conveyor system)

Overview

- The Prairie Flexiveyor evolved from the original bridge conveyors first installed in Canadian potash mines in the early 1980s. The early bridge conveyor systems were found to be cumbersome, expensive to operate and repair, suffered from poor availability, and had a number of inherent safety risks. This led Prairie to develop their first generation system which commenced operation in a Canadian potash mine in 1990, with second and third generation systems subsequently evolving from this design.

- Currently there are 18 units in operation, including one original Generation I system, ten Generation II systems, and seven Generation III systems, of which two Generation III systems are utilised in underground coal mines.
- The Flexiveyor consists of a series of 6 metre-long, wheel mounted, interconnected cars. Each car is fitted with a short (rubber) conveyor bridge which conveys product from inbye and transfers it to the next outbye conveyor bridge. The design of the cars/conveyor bridges allows some 60 degree articulation between cars, which enables the Flexiveyor to negotiate 90 degree curves of 9 m radius (although 60–70 degree turns are preferred).
- The Flexiveyor currently comes in three configurations, all 2.5 metre-wide; a 1.78 metre-high Standard configuration, a 2 metre-high Straddle Over configuration, and a 1.2 metre-high Low Profile configuration. As suggested, the Straddle Over model straddles the panel conveyor end to discharge product whereas the other two models are designed to run alongside and side discharge onto the panel conveyor.
- A computer controlled ”Robotram” tramming control system was introduced with the Generation II design to allow operation of the system by one operator with a radio remote control. The operator steers the first inbye car and the Robotram system then steers each subsequent car through the same position. Provision is made for the Robotram system to be overridden to allow an individual car to be re-tracked in the event of misalignment. The Flexiveyor can also be fitted with rib-following capabilities to enhance the steering functionality.
- Each car is fitted with an automatic belt tracking system, while head and tail rollers are designed to be self-cleaning.
- A Queensland colliery has been utilising a Generation III in bord and pillar operations since early 2008, albeit on an infrequent basis due to mine design constraints, and has introduced a number of modifications and improvements making the system more fit for purpose for an underground coal application. This colliery also secured a second Generation III from South Africa and is currently replicating the improvements on that system.
- A mining company also intends to introduce a short longwall mining system at this colliery and the Generation III was redeployed to gateroad development, introducing two entry panels with 50 metre-long pillars.
- An auxiliary ventilation system is fitted to the modified system with two runs of 800 mm diameter ducting fitted above the bridge conveyors. (Figure 9). Fixed ducting is fitted along the bridges with flexible ducting used between the bridges to facilitate articulation of the cars. The auxiliary fan and DCB is mounted on a ’dummy’ car outbye at the conveyor discharge with a Bretby Cable Handler used to manage the cables beside the Flexiveyor.

Figure 9. Prairie Flexiveyor undergoing surface commissioning at an Australian colliery

(Prairie, N.D.)

Final Review

- The DMS/Prairie Flexiveyor is essentially a mature technology adapted from the Canadian potash sector, and has benefited from some three years operational experience at a Queensland colliery, developing a system which meets underground coal regulatory standards and mining conditions. The Development Flexiveyor now proposed has essentially been scaled down to allow a DMS/Atlas Copco Coaltram CT08 LHD to operate beside the conveyor to undertake the materials re-supply function. It is quite possible that this narrow conveyor configuration may allow other materials re-supply technologies to be employed, such as a monorail mounted Scharf-style system.
- 3D modelling of the proposed system is necessary (and is reportedly under development) to demonstrate that the continuous haulage, materials re-supply and face services functions can be safely and effectively operated within the proposed 5.2 metre-wide, 2.8 metre-high (minimum) roadway profile, particularly in regards to access in and around intersections and cut-throughs.
- DMS/Prairie also propose to utilise a standard height side discharge configuration to allow the development Flexiveyor to run beside the longwall conveyor, and not straddle the conveyor as currently practiced at the Queensland colliery. This will allow the overall height of the system, including ventilation ducting, to be reduced to some 2.64 m. The proposed narrower conveyor should meet the 10 MPOH functional specification. A surge hopper and sizer would be required due to the use of this narrower conveyor and to minimise spillage at transfers points located through the system.
- Subject to gaining necessary approvals, DMS/Prairie propose to utilise sonar technologies recently developed for potash applications to enhance the overall rib following capabilities of the system and to separately replace the optical sensors currently utilised for conveyor belt tracking.
- While the drive system is proven technology in the potash sector, it may be necessary to verify its suitability and steer ability in an undulating, irregular coal seam application.
- Given that the system comprises a number of cascading conveyors, the overall system availability is limited by the individual availability of each of these cars. For example, an individual availability of 99.5% could result in a system availability

approaching 85%, with an individual availability of 99% resulting in a system availability of around 72%.

3. CHALLENGES INTEGRATING THE CONTINUOUS HAULAGE TECHNOLOGIES IN GATEROAD DEVELOPMENT

The review process identified a number of what have been termed either 'fatal flaws' or "areas of significant concern" with respect to the technologies evaluated. These are summarised in Section 3.1. Additionally, further design and operational considerations have been determined and summarised. Even though certain issues have been identified, this is by no means a reason to discount these technologies, as the OEMs and associated parties, for the most part, have taken these findings on-board and are endeavouring to find solutions to enhance the potential success of each party's technologies for future gateroad development application.

3.1 CONCERNS

Bridge Conveyors

1. The control technologies currently employed require an operator on each pair of bridges which would result in upwards of eight bridge operators necessary in a gateroad development system, increasing the risk of unplanned movements and personal risk exposure to moving components.
2. The overall geometry of conventional bridge conveyor systems coupled with the limited steering ability of the track mounted system precludes integration with the materials re-supply function.
3. The physical size of the standard Prairie Flexiveyor (2.5 metre-wide) would make integration of the CHS and materials re-supply function challenging in gateroad development. The development of a narrow Flexiveyor and utilisation of a narrow LHD may assist to address this.

Tube/Pipe Conveyors

4. Conventional pipe or tube belt conveying systems are unsuitable due to the high belt tensions utilised in those systems and the large turning radii.
5. The design and construction of the standard/existing SICON conveyor system (as proposed in Sandvik's VACHS 500 conveyor) was considered inherently flawed for application in a mobile, flexible application in undulating seam conditions likely to be found underground in gateroad development.
6. The inability of the Bosmin CAP conveyor to track behind the miner as it advances through the cut-through and into the adjacent heading due to the suspension of the CAP conveyor from the OEM self-advancing roof-mounted twin-rail system was considered a fundamental flaw.
7. The inability of the current Premron E-BS design to negotiate the radius turns required for the relevant gateroad application was similarly considered a restriction in its application of longwall gateroad development.
8. Currently available closed conveyor systems (e.g. SICON, Premron E-BS and ICS) are typically used in fixed plant (static) applications and there is a lack of

appreciation or understanding as to how they will perform in a dynamic/mobile application, particularly with respect to

–the tracking and loading of conveyors
–product surges
–pendulum effects resulting from advancing, retreating and shuffling the system
–the location and effectiveness of drives

9. The closed conveyor systems considered in this study (for example, Sandvik VACHS 500, Premron E-BS, ICS and Bosmin CAP) require ROM product to be sized to <100 mm and also require product flow to be regulated to prevent overloading. All these systems would therefore require a hopper car/sizer located immediately behind the continuous miner.
10. All closed systems are exposed to the risk of blockages in the event that slabby material or strata support materials (roof bolts for example) are inadvertently loaded into the conveyor. These slabs also have the potential to inflict belt wear or possibly even tears in belting. Removal of such blockages will pose challenges, particularly when the conveyor system is positioned at height.
11. The Sandvik VACHS 500, Premron E-BS and ICS conveying systems also require a relatively large diameter, vertically mounted tail pulley to be located in this general region, and an extended loading system to transfer product from the hopper car/sizer to the conveyor loading station. The size and configuration of the hopper car/sizer, tail pulley and loading mechanism have the potential to limit access to the continuous miner and also impact the material resupply function unless properly integrated.

3.2 DESIGN AND OPERATIONAL CONSIDERATIONS

Throughout the review process, a number of design and operational considerations were identified with respect to the potential design and application of a continuous haulage system in gateroad development, including the following:

1. It is preferred that the selected system be synergistic with longwall operations, utilising the longwall conveyor during development, and also utilising the longwall monorail system, if in fact a monorail is required.
2. A number of the systems identified have proposed suspending the CHS off a monorail together with the ventilation and other face services, to form a totally integrated development services system.

    - This would require some form of transfer or discharge system to be employed to transfer coal from the longwall monorail alignment to the centre of the conveyor alignment, a distance of 3 m or more.
    - Some form of cantilever support would be required (not easy) and a trolley mounted on the longwall conveyor for correct discharge (and subsequent rails installed).
    - Therefore, it is likely that any monorail mounted CHS would require a separate monorail system to that subsequently employed for longwall services, one that is centrally located to the longwall conveyor alignment.

3. The additional CHS monorail system (mounted over the centre of the panel conveyor) would then allow the other face services (e.g. ventilation, power, water, pump-out, communications, etc.) to either be integrated within the CHS monorail system, or separately mounted on the longwall monorail.
4. It is likely that some, or all, roof mounted conveyor options will require a minimum 3 metre-high roadway along the panel conveyor to allow end discharge onto the conveyor.
5. Monorail or roof mounted systems are likely to introduce challenges with respect to the inspection, testing and maintenance of both suspension rollers and conveyor idlers.
6. Consideration will need to be given to monorail mounted systems with respect to the pendulum effect created when advancing or retreating through cut-throughs, particularly if there are any repeated shuffling of the system or surges in product flow.
7. Floor mounted systems have the potential to track out of alignment and also be more sensitive to the effects of floor cross-grades and variable floor conditions. Suitable levels of redundancy will be required in navigation and proximity detection and collision avoidance systems to ensure systems are not exposed in the event of single sensor failure.
8. The introduction of a CHS into the gateroad development process will introduce challenges with respect to routine advancement of the panel (longwall) conveyor and access along the conveyor roadway (e.g. limiting the capacity to fully inspect the panel conveyor).
9. One of the difficulties reported with earlier roof mounted Joy 2FCT installations was the requirement to install a centre bolt to hang the centrally located 2FCT monorail. Even today, the design of continuous miners does not allow the installation of a centre bolt off the miner, and therefore any requirement to install a centre hanging bolt for a monorail mounted CHS may again prove problematic.

4. DISCUSSION / SUMMARY

In the course of this review, it has been found that not one of the technologies identified in the study was considered to satisfactorily meet the functional requirements of a 10 MPOH Continuous Haulage System.

The technologies identified ranged from being technically immature to technically mature, albeit that the technically mature technologies were largely unproven in a mobile, flexible application as required for gateroad development. It was also evident that few of the developers/OEMs of closed conveyor systems had given serious consideration to the challenges posed in transporting systems underground and in panel to panel relocations.

The five short-listed systems identified in this study (e.g. Bosmin CAP, Premron E-BS, ICS, Sandvik VACHS 500 and DMS/Prairie Development Flexiveyor) all require some degree of product sizing and control to regulate product flow. This will require a surge hopper and sizer car located immediately behind the continuous miner, which may then present additional challenges with regard to integration of the material’s re-supply and face services functions.

Roof mounted systems such as the Bosmin CAP, Premron E-BS, ICS or Sandvik VACHS all have the advantage of being trapped systems and therefore have minimal risk of misalignment. However, all require installation of the roof mounted monorail or dual-rail system at the immediate face to allow the haulage system to advance behind the continuous miner and surge hopper/sizer.

All of the short-listed developers/OEMs interviewed during the review process expressed concerns regarding the challenges faced by OEMs gaining traction to take their respective systems forward. Smaller OEMs have major difficulties integrating their technologies with other suppliers, while major OEMs, that have the potential for being a ’one-stop-shop’ supplier, similarly face challenges obtaining traction for development of an integrated system at corporate level (internally) and also externally across the industry. All OEMs recognise the benefits of working with any industry representative group to progress development of their respective systems, to facilitate networking among key OEMs/suppliers, to develop a business case for the introduction of continuous haulage in gateroad development, and to improve the industry’s appreciation of that business case.

The review has not, at this stage, been able to identify any specific continuous haulage system that could be readily applied to longwall gateroad development to an acceptable level of technical and operational risk. Some systems require substantive research and/or demonstration to satisfy reviewers that inherent technical risks have been addressed to a level that would warrant their further consideration as part of an integrated, high capacity roadway development system. Research opportunities and/or requirements have been identified for each short-listed technology and a list has been provided to each relevant supplier/OEM for further consideration, R&D, ACARP funding applications, and so forth.

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