THE RAIL CONVEYOR – A NEW ENERGY EFFICIENT CONVEYING TECHNOLOGY

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ABSTRACT

Current trends within the mining industry have called for much more efficient systems for the transportation of bulk materials. These systems are typically required to transport many millions of tonnes of bulk materials over many kilometres every year with the transportation method used being dependent on the terrain to be conveyed over, the required throughput of the bulk material and transportation distance. The demand for increased efficiency and throughput has entailed much research and has seen significant improvements over the past few decades.

This paper describes a new conveying technology for the continuous transportation of bulk materials. The new technology, aptly named the Rail Conveyor, merges the benefits of both belt conveyor technology and railway to produce a continuous low rolling resistance bulk material transportation system. This step change technology provides a more energy efficient and cost effective method for transporting bulk commodities over long distances and has many advantages over conventional overland belt conveyors. Some of the advantages include; capital and operating cost savings, reduced energy consumption and the ability to transport over longer distances due to reduced cumulative belt tension within the system. This paper will discuss the working principle of the Rail Conveyor system, the development of the technology, laboratory and site testing, in addition to a cost comparison to conventional belt conveyors.

1. INTRODUCTION

The increasing demand for the extraction of ore and minerals, coupled with more stringent environmental legislation has driven the need for more energy efficient systems to transport bulk materials from the mine site to processing plants, power stations and export terminals. Transportation distances and terrain vary considerably depending on the operational requirements, where the choice of material handling system in almost all cases will rely on belt conveyors, in combination with haul trucks and/or railway systems. The combination and use of each type of transportation system will depend on the transportation distance, throughput and terrain.

The transportation of bulk materials overland is typically accomplished using trains, trucks or conveyors, with each of these applications having both their advantages and disadvantages. Trucks are typically used for shorter transportation distances requiring smaller throughputs where the transportation path may vary, or where the terrain prohibits the use of conveyors or rail. Additionally, trucks are often used for short-term haulage operations, where the capital cost of fixed plant is not warranted. Conversely, rail is the preferred option for long-term operations requiring relatively long transportation distances, where the number of trucks to transport the same amount of material over the same length would be impractical in terms of cost and labour.

Belt conveyors being continuous, rather than a batch transportation system, have considerable economic, operational and maintenance advantages over both truck and rail. Significant developments in low rolling resistance conveyor belting has seen reduced energy consumption of belt conveyors, meaning installations have become progressively longer and more economically competitive with railway. Figure 1 shows the progressive increase in single flight belt conveyor lengths from 1980, with belt conveyors in excess of 30 km long already being planned. The longest single flight overland belt conveyor in the world is currently the Impumelelo Overland Conveyor in South Africa. This particular system was commissioned in 2015, is 26.7 km long, and transports coal to Sasol's Synfuel Plant in Secunda at a design capacity of 2,400 t/hr (Frittella and de Necker [1]).

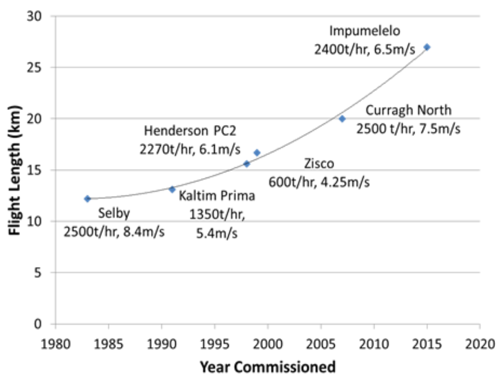


Figure 1. World's longest single flight belt conveyors

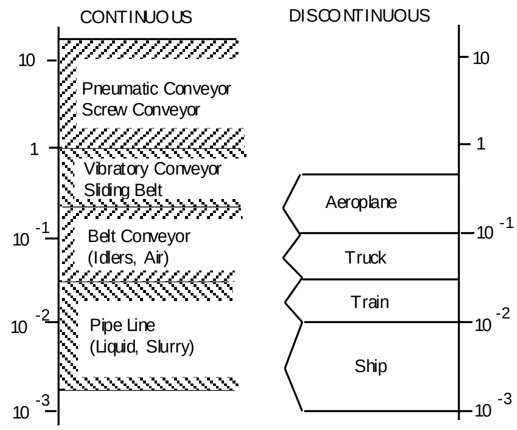


Figure 2. Loss Factor of Transportation for bulk material handling systems (Jonkers [4])

With the demand for automated mining operations, belt conveyors have clear operational advantages. However, due to the inherent motion losses of transportation, the rolling resistance of a belt conveyor is greater than both trucks and rail. This is despite recent advances in the energy efficiency of belt conveyors resulting from low rolling resistance bottom cover compounds, and variable speed control and equipment level intervention (Zhang and Xia [2,3]). The motion losses of belt conveyors effectively limit the operational length and cost effectiveness of conventional overland conveyors.

The relative efficiencies of each of the major bulk material transportation systems, identified above, are reflected in the Loss Factor of Transportation, calculated by Jonkers [4] and shown in Figure 2. Jonkers divides the major bulk material transportation systems into continuous and discontinuous systems and clearly shows the benefits of railway over trucks and trucks over belt conveyors. This comparison is largely influenced by the rolling resistance factor of each system, with long overland belt conveyors ranging from 0.009 to 0.017, trucks around 0.006 (Lodewijks and Welink [5]) and rail approximately 0.001 to 0.002 (Avallone et al. [6]). This can be best explained by comparing the rolling resistances for each system, excluding the efficiencies of the drive systems. The rolling resistance of belt conveyors is known as the main resistance and includes the belt and bulk solid flexure resistance, the rotating resistance of the idler rolls and the indentation rolling resistance of the conveyor belt. Research by Hager and Hintz [7], and more recently Wheeler [8,9,10], has shown the indentation rolling resistance and belt and bulk material flexure resistance typically accounts for more than 80% of the total power consumption of long horizontal conveyors. By comparison the rolling resistance of trucks is due to the interaction between the rubber tyres and the road, while rail has the lowest rolling resistance due to steel wheels running on steel tracks.

Despite the inefficiencies of belt conveyors, research by Saxby and Elkink [11] has shown belt conveyors are more cost-effective on a life-cycle cost basis than both truck and rail transport for throughputs up to 5 million tons per annum over horizontal conveying distances up to 40 km. This research is further confirmed by Galligan [12], with Figure 3 (a) showing the capital versus operating cost comparison for rail, overland belt conveyor and trucks. While the capital cost for rail per kilometre is greater than belt conveyors and trucks, the operating cost for rail is less, meaning that as the transportation distance increases the higher initial capital investment is offset against lower operating cost. This is highlighted in Figure 3 (b), where the economic benefit of rail for long distance transportation is demonstrated. Clearly, the relative operating cost comparisons are heavily dependent on their Loss Factor of Transportation (Jonkers [4]), with infrastructure costs gradually being outweighed by reduced energy costs as a result of lower rolling friction.

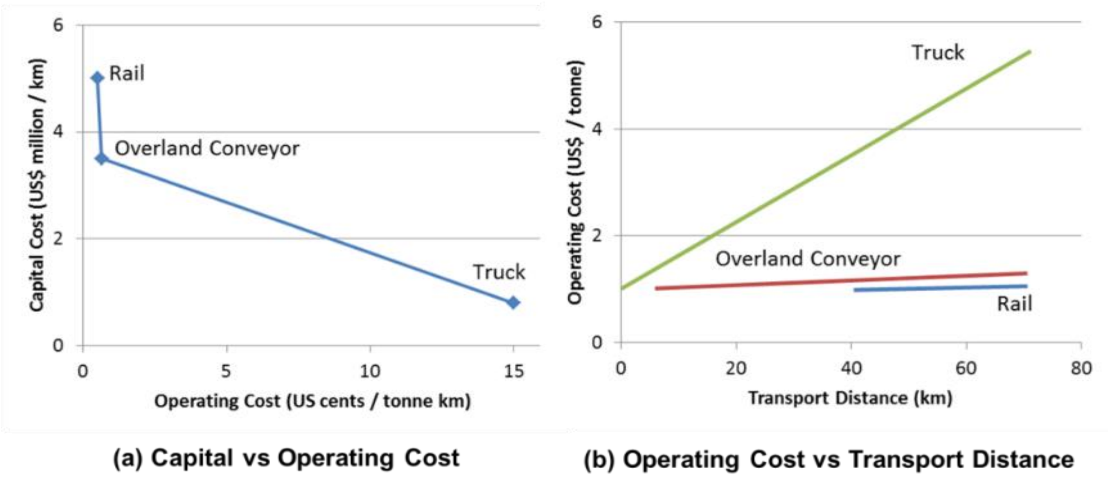


Figure 3. Cost analysis for truck, rail and overland belt conveyors (Galligan, 2011)

As new mineral and ore deposits are mined further from existing processing plants, power stations and ports, the transportation of bulk materials over longer distances is becoming essential to many of our most critical industries. Future long distance bulk material transport systems must not only be cost effective, but highly energy efficient, as reducing the energy intensity of operations is a key objective for all global resource companies. The limitations for conventional belt conveyors is the interaction between the rubber covered belt and idler rolls, meaning the efficiency of railway transportation with rolling efficiencies of 0.001 to 0.002 (Avallone et al. [6]), will never be matched by systems supported by conventional idler rolls. With these objectives and limitations in mind, a new rail based continuous bulk material transportation system has been developed. The new technology is aptly named the Rail Conveyor due to its combination of two well-established transportation technologies. This paper will introduce the Rail Conveyor system, the development and verification process, and present a cost analysis of the new technology compared to conventional belt conveyors.

2. RAIL CONVEYOR SYSTEM

The Rail Conveyor is a novel invention that combines the primary advantages of both belt conveying and railway systems (Wheeler [13,14]). The Rail Conveyor, shown diagrammatically in Figure 4, is a continuous bulk material transportation system that shares a rolling resistance similar in magnitude to railway systems due to track wheels running on rails.

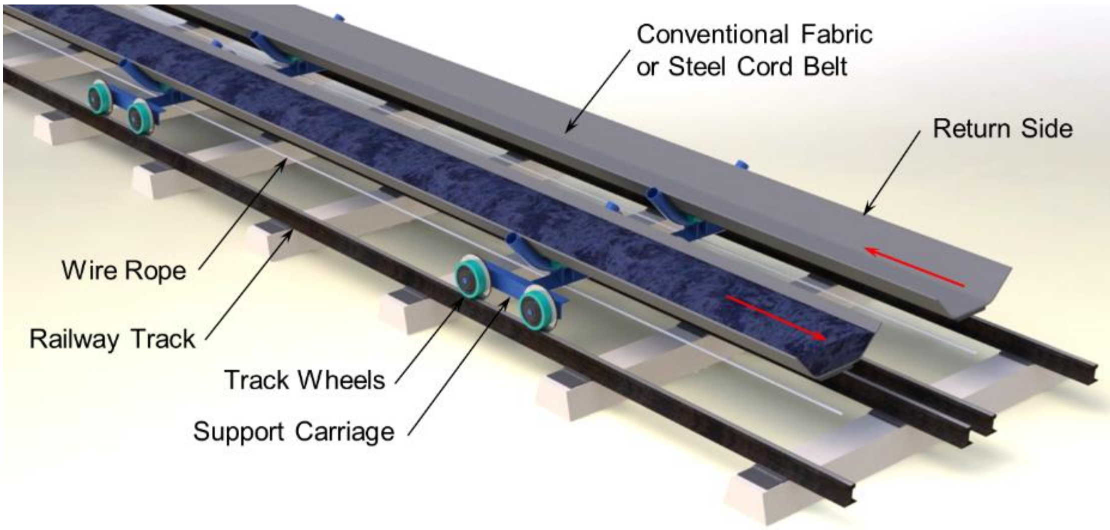


Figure 4. Rail Conveyor concept

The Rail Conveyor system transports bulk material, and is driven, like a conventional belt conveyor. The bulk material is supported by a conveyor belt that is driven by one or more localised drive pulleys, however, rather than being supported by idler rolls the belt is supported by a series of linked carriages. The carriages utilise steel or nylon track wheels that run along light gauge steel railway tracks. The belt is not physically fixed to the support carriages, but drives each carriage by friction developed between the belt and the carriage yoke. The support carriages are clamped to an endless wire rope, typically via a spring, and equally spaced along the length of the system. The support carriages follow a continuous path around the conveying system, supporting the bulk material and belt along the carry side, and the belt on the return side. The system can be configured in a side-by-side configuration (as shown in Figure 5), or alternatively, with the return side positioned directly above the carry side (as shown in Figure 6) to reduce the footprint of the system. In the latter case, the more heavily loaded carry side can be supported by ground based sleepers, while the return side is positioned above due to the need for less structural support.

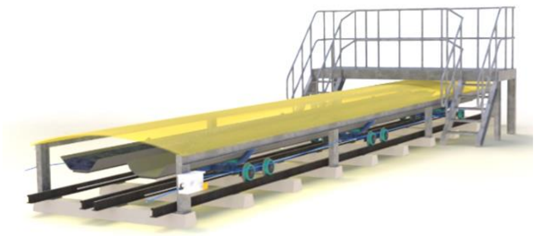


Figure 5. Side-by-side configuration

Figure 6. Carry side beneath return side

Figure 7 shows a typical configuration of the Rail Conveyor system. The belt is loaded in a conventional manner as shown in Figure 8, with the belt supported by sets of conventional idler rolls prior to being delivered to the support carriages of the Rail Conveyor system. The belt is driven using conventional belt conveyor technology, incorporating one or more drive pulleys and a take-up system, as detailed in Figure 9. The carriages support the belt until just prior to the discharge point, where the belt then lifts off the carriages and is once again supported by conventional troughed idler rolls. The bulk material is discharged in the same manner as a conventional belt conveying system, with the belt traveling around a head pulley and belt take-up (tensioning) system before being either turned over via a conventional belt turnover, or simply guided directly back on to the support carriages for the return side run.

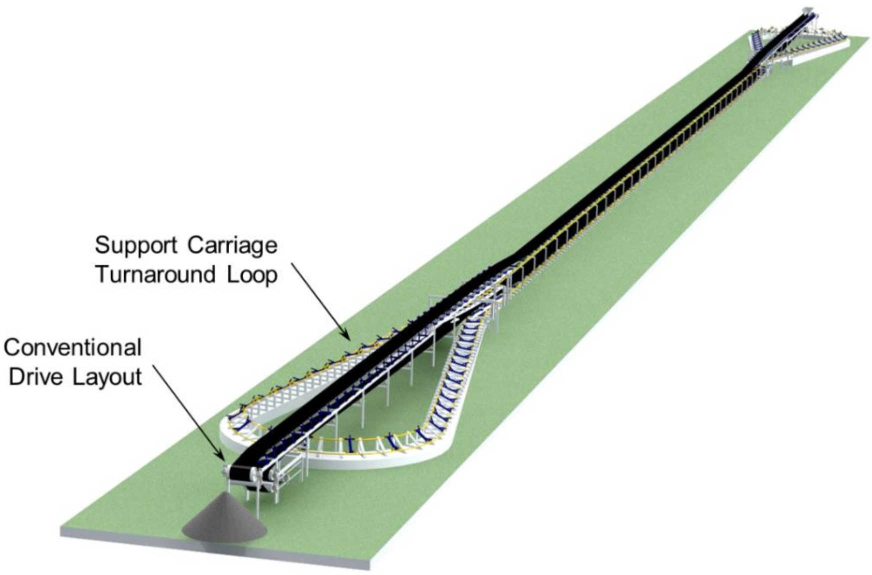


Figure 7. Horizontal carriage turnaround configuration

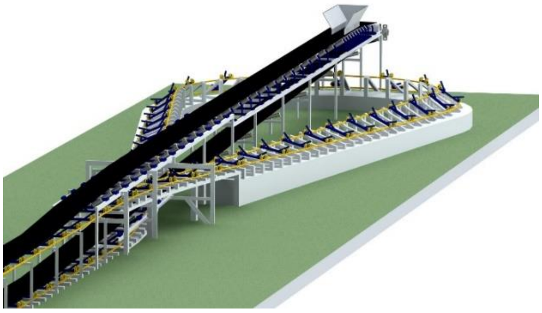


Figure 8. Loading point and carriage turnaround

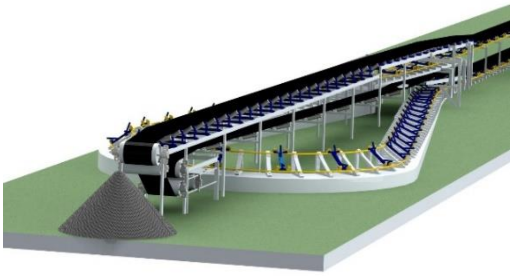


Figure 9. Discharge point and drive layout

The carriages are turned around at each end using a horizontal turnaround loop as shown in Figure 7 to Figure 9, or alternatively, a vertical turnaround wheel as shown in Figure 10. The vertical turnover option reduces the footprint of the system at the head and tail end. The turnaround methods of the Rail Conveyor system not only redirect the carriages from the carry side to the return side, and vice versa, but also act as take-up systems for the carriages to allow for the differential stretch between the conveyor belt and the cable between the carriages. In the case of the horizontal turnaround this is achieved by a leaf spring attached to each carriage that tensions the interconnecting cable. The spring acts to shorten or extend the relative distance between each carriage to allow for changes in belt length. The distance that the carriages travel around the turnaround loop is primarily determined from the carriage design that establishes the minimum turnaround radius. Additionally, the cable tension and the distance required for the carriages to compensate for the change in belt length during starting, running and stopping conditions that will be experienced are also considered for the turnaround loop of the system. Similarly, the vertical system relies on the carriage turnaround wheel acting as a horizontal take-up that facilitates horizontal movement while maintaining a suitable pre-tension in the cable.

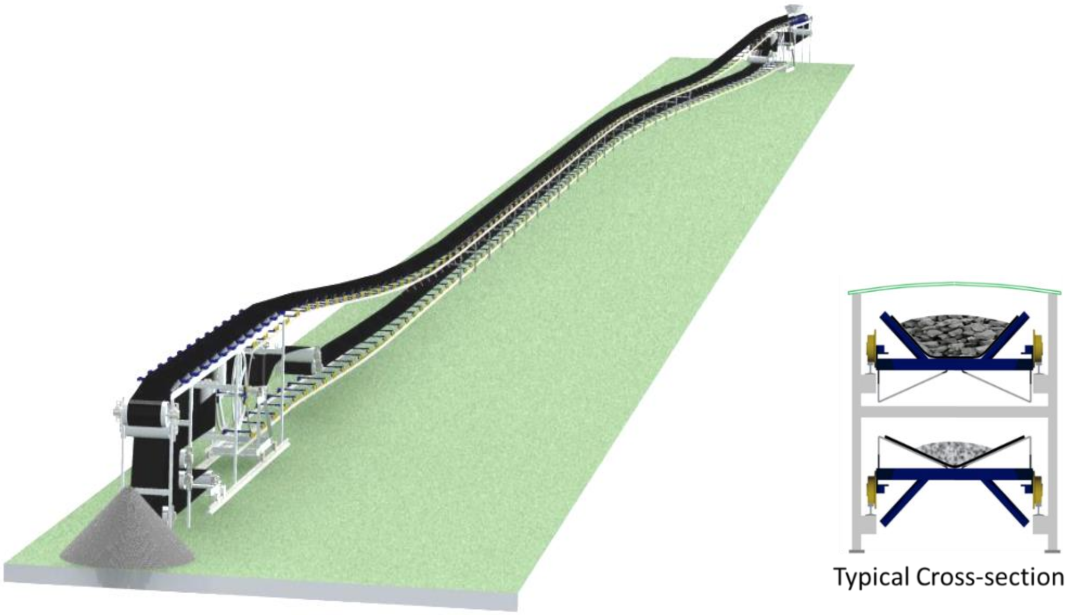


Figure 10. Vertical carriage turnaround configuration

The primary advantage of the Rail Conveyor system is that the major resistance components of a conventional belt conveyor are eliminated. Since the belt rests on the support carriages during transportation there is no relative movement between the carriages and the belt, and therefore no belt or bulk material flexure resistance or indentation rolling resistance. The main resistances to motion of the new technology is the rotating resistance of the bearings within the track wheels and the rolling friction of the track wheels on the light gauge rail, leading to a highly efficient transportation system akin to railway.

The lack of relative movement between the belt and the support carriages results in significantly less movement of the bulk material and therefore has many other advantages over conventional belt conveyors. These include; increased belt speeds, better bulk material stability through horizontal curves, less degradation of the bulk material resulting in less dust generation, and less belt cover wear and lower flexure induced stress.

3. PROOF OF CONCEPT

An integral part of the successful development of the Rail Conveyor system was the construction of a number of 1:10 scale models. The scale models are shown in Figure 11 to Figure 13 in the TUNRA Bulk Solids Laboratory at the University of Newcastle. The models were manufactured using 3D printed and scale model railway parts and designed to transport minus 8 mm gravel. The working models allowed the Rail Conveyor concept to be proven at a laboratory scale and greatly assisted in the design of the prototype system. Figure 11 and Figure 12 show the horizontal turnaround system. This particular system was designed to convey in both directions in a side-by-side recirculating configuration for ease of use. Despite a relatively short conveying length, sufficient friction was mobilised between the carriages and the belt to pull the carriages around the two horizontal end loops, thus proving the principle of operation. Furthermore, it was clearly demonstrated that the friction to drive each carriage is quite low, needing only to overcome the rolling friction of each carriage, in addition to any weight component when travelling up or down inclines.

Figure 11. 1:10 Scale model system

Figure 12. Two way transportation

Figure 13 shows the scale model vertical carriage turnaround system. In this case the carry side is above the return side as per a conventional conveyor, but can be reversed (as per Figure 6) depending on the length of the installation. The vertical carriage turnaround system formed the basis of the prototype system that was successfully commissioned in China in July 2015. The prototype system, pictured in Figure 14, is 150 m long, has a belt width of 1.2 m and operates at belt speeds up to 4 m/s. The system was built by LIBO Heavy Machine Technology Corporation Ltd. The successful commissioning and operation of the prototype system proved the Rail Conveyor concept and has provided an invaluable means to evaluate and test a wide range of system variables.

Figure 13. Vertical turnover scale model system (shown in foreground)

Since commissioning the prototype system, the facility has been used to better understand the operational characteristics of the Rail Conveyor system via experimental measurement. Experiments have focused on measuring the dynamic response of the system during starting, steady state operation and stopping, belt and carriage interaction, cable tension, noise generation, and track wheel and rail interaction.

Figure 14. Prototype system operating in China

Figure 15 shows a typical conveying section of the Rail Conveyor where the prototype system has the carry side above the return side similar to the scale model. The configuration shown in Figure 15 has the carriages at a pitch of 3 m, however due to the lack of relative movement between the belt and the carriage, scope exists to increase sag ratios in comparison to conventional belt conveyors.

Figure 16 shows a carriage on the prototype system just before the belt is redelivered after the turnaround loop has been negotiated. The symmetrical form of the carriages enables the vertical turnaround to be utilised without the need for the carriages to be inverted for the return side.

Figure 15. Conveying section of prototype system with carry side above

Figure 16. Carriage of prototype system before belt feeding section

4. RAIL CONVEYOR TESTING

To fully understand how the Rail Conveyor system will operate on an industrial basis, it is necessary to test certain variables to assist in the design and feasibility of future systems. By understanding the operational requirements of the system, the accuracy of feasibility studies in relation to both the capital and operational cost requirements will give greater confidence in the technology. The following section will outline some of the testing that has been completed on the Rail Conveyor system.

4.1 TENSION DISTRIBUTION

An important design consideration for the new technology is the need to accurately predict the tension requirements of the cable linking the carriages. To investigate the cable tension, experiments were undertaken using an instrumented carriage to measure the tension in the cable during starting, steady state operation and stopping, for both loaded and unloaded cases. The cable tension is measured via a 2000 kg load cell that transmits data via a wireless transmitter, shown in Figure 17. The measurements provide valuable data to better understand the interaction between the carriage and the belt during operation and forces on the carriages throughout the turnover sections.

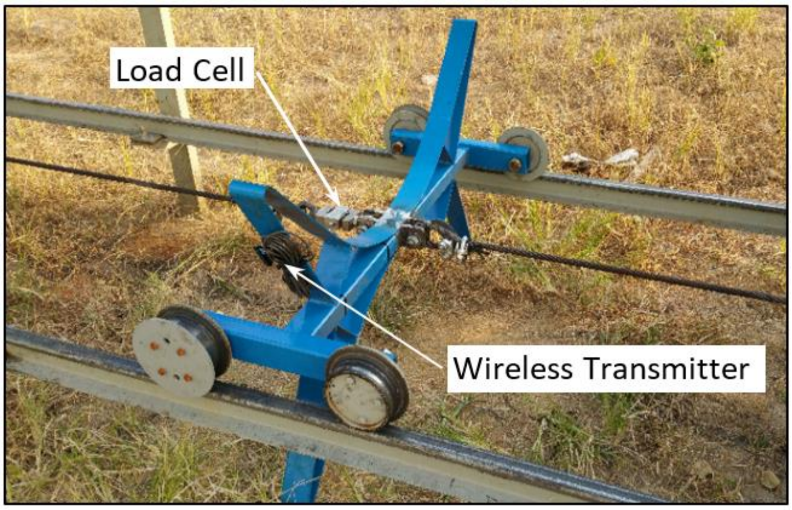


Figure 17. Cable tension measurement on prototype

Measured cable tension data is shown in Figure 18. The data clearly shows that the tension in the cable reduces along both the return and carry side when the belt is supported by the carriages. When the belt lifts off the carriages, the cable tension peaks, and then increases as the carriages are pulled around the vertical turnover wheels at the head and tail end of the system. The drop in cable tension along the carry side and return side demonstrates that the running tension in the system is fully supported by the conveyor belt itself.

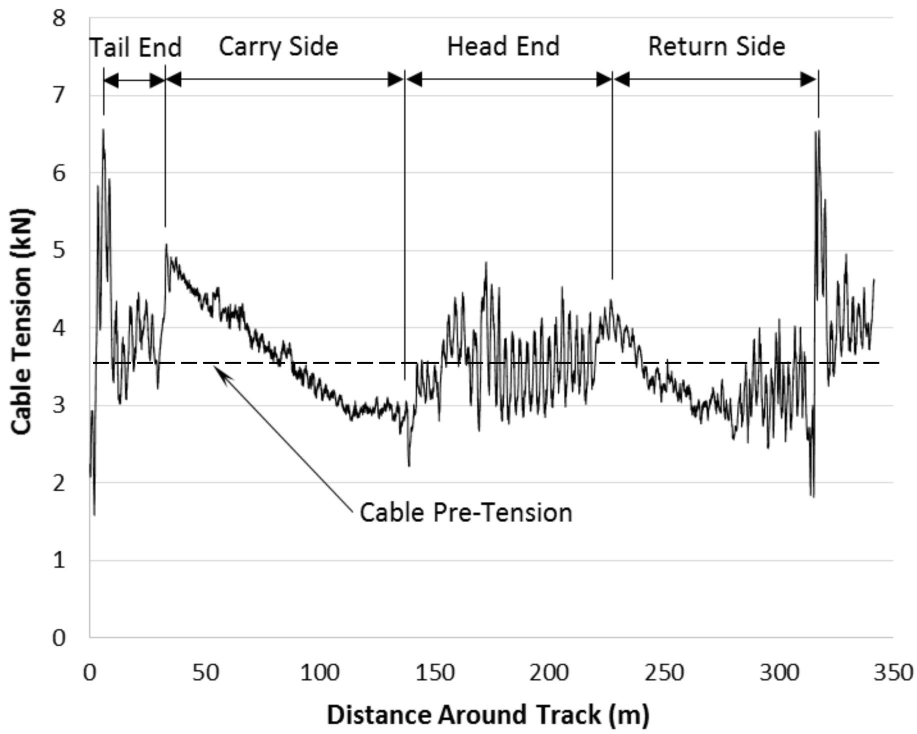


Figure 18. Cable tension for one track cycle

4.2 FRICTION FACTOR MEASUREMENTS

Laboratory experiments were undertaken to quantify the energy reduction likely from the Rail Conveyor technology. The investigation involved simple drag tests, in addition to more complex combined radial and axial load tests involving a number of different potential track wheel materials.

While there is much published literature on the rolling resistance of conventional railway systems, the influence of smaller diameter track wheels and significantly lower radial loads are not readily available in published literature. Figure 19 shows initial drag measurements undertaken using steel wheels attached to trailer axle hubs containing back-to-back tapered roller bearings. Experimental results showed friction factors of 0.004 to 0.005 despite the use of tapered roller bearings, which typically exhibit significantly greater rotational resistance than deep groove ball bearings. More recently, track wheel wear is also being investigated to select the most cost effective material from which to manufacture the track wheels. Figure 20 shows a laboratory test facility designed to measure track wheel wear and rotational resistance under combined radial and axial loading.

Figure 19. Laboratory test equipment to measure rolling resistance

Figure 20. Laboratory test equipment to measure track wheel wear and friction

To gain a better understanding of the friction factor of the Rail Conveyor system a series of tests were completed on different track wheel materials. The materials that were tested included plastic, several grades of nylon and cast iron. To determine the difference between the contact friction between the track wheels and the light gauge rail and the rotational resistance of the wheels, two sets of tests were completed. The first test that was completed was rim drag testing, shown in Figure 21, which gives a quantifiable measure for the rotational resistance of the bearings, sealing arrangement and grease. The second test utilised the laboratory test equipment shown in Figure 20 that measures the rim drag, in addition to the contact friction between the track wheels and the light gauge rail. This was achieved by recording the total resistance of the track wheel under load and subtracting the rim drag value to give an overall contact friction factor for each of the materials that were tested.

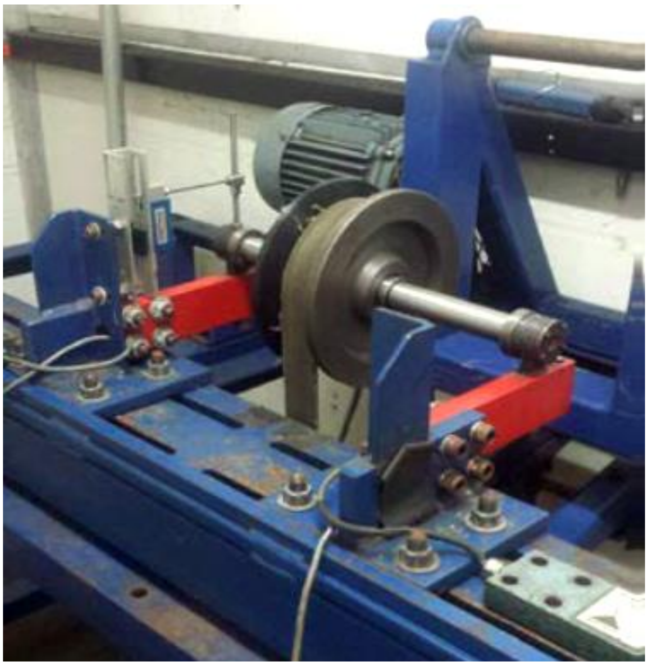


Figure 21. Rim drag testing apparatus for track wheels

Rim drag tests were conducted using the testing apparatus shown in Figure 21. Tests were performed at 20°C, at a constant velocity of 4 m/s and a radial load of 250 N. The track wheel assembly comprised of a neoprene lip seal and two deep groove ball bearings. The average rim drag value measured was 4.0 N per wheel.

Once the above testing was complete the contact friction values for each track wheel was determined. These tests were undertaken at the same temperature and velocity conditions as the rim drag testing. Figure 22 shows the friction factor versus radial load for wheels manufactured from two grades of nylon (shown as A and B) and cast iron. Data with, and without the rim drag are presented to show the influence of the rim drag, particularly at lower radial loads.

Results show similarity between nylon B and the cast iron, while nylon A is significantly higher, most likely since it is a softer grade of nylon than B. For the radial loading condition, it was found that at higher loads (representative of a fully loaded system) the friction factor (including rim drag) was in the range of 0.004 to 0.005. While at lower loads the inclusion of the load independent rim drag value sees a significant increase of the friction factor for all materials.

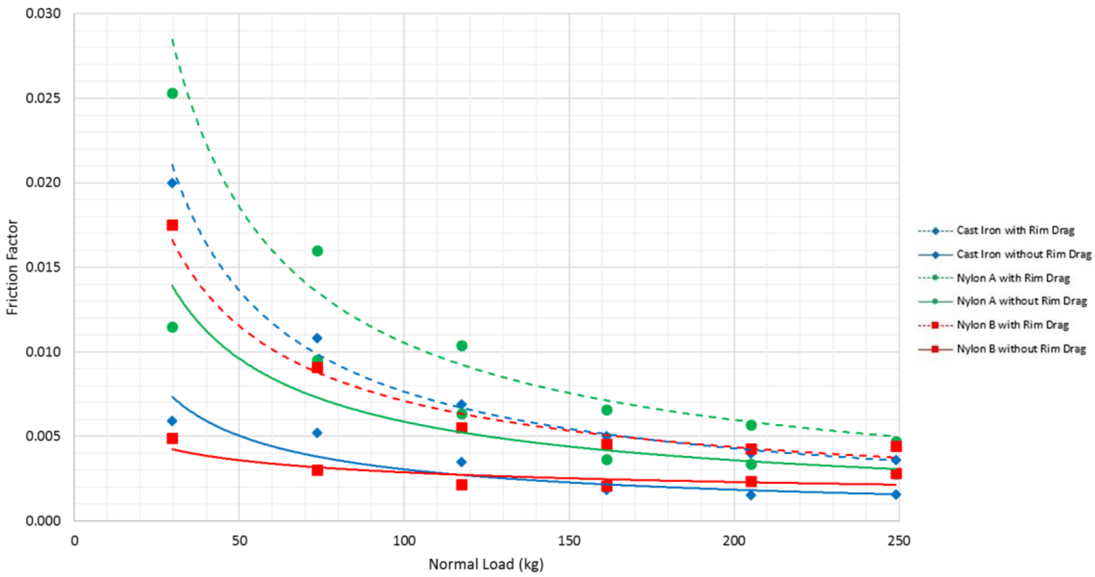


Figure 22. Track wheel friction versus radial load (Ellis [15])

To analyse the variation of the friction factor through horizontal curves, additional testing incorporating axial loading was undertaken. Like conventional belt conveyors the Rail Conveyor relies on tilting the carriages, and therefore the tracks, throughout horizontal curves to balance the belt tension forces. Figure 23 shows the forces acting on a carriage while traveling through a horizontal curve. The induced axial load from the belt tension, T, will result in increased friction due to the potential interaction of the flange radius and the rail head. This effect is simulated by an axial load (in addition to the normal load) applied to the track via a cable and suspended mass shown diagrammatically in Figure 24.

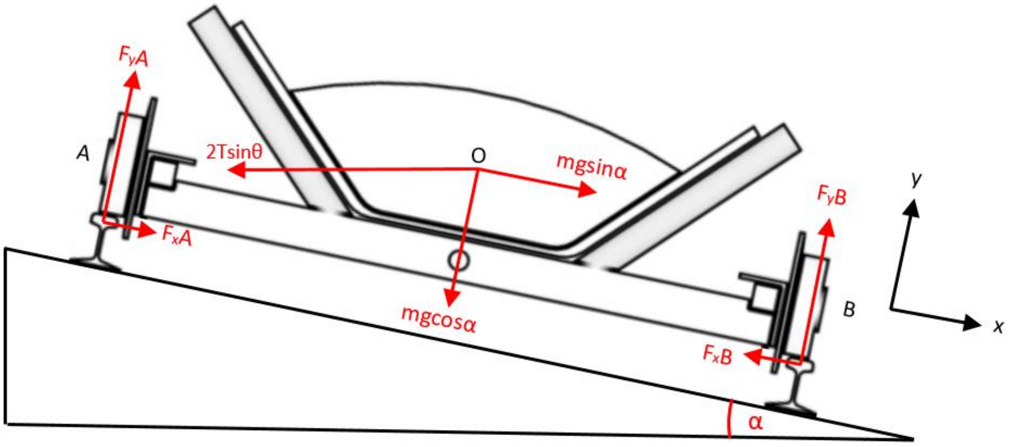


Figure 23. Schematic of forces acting on carriage through horizontal curve

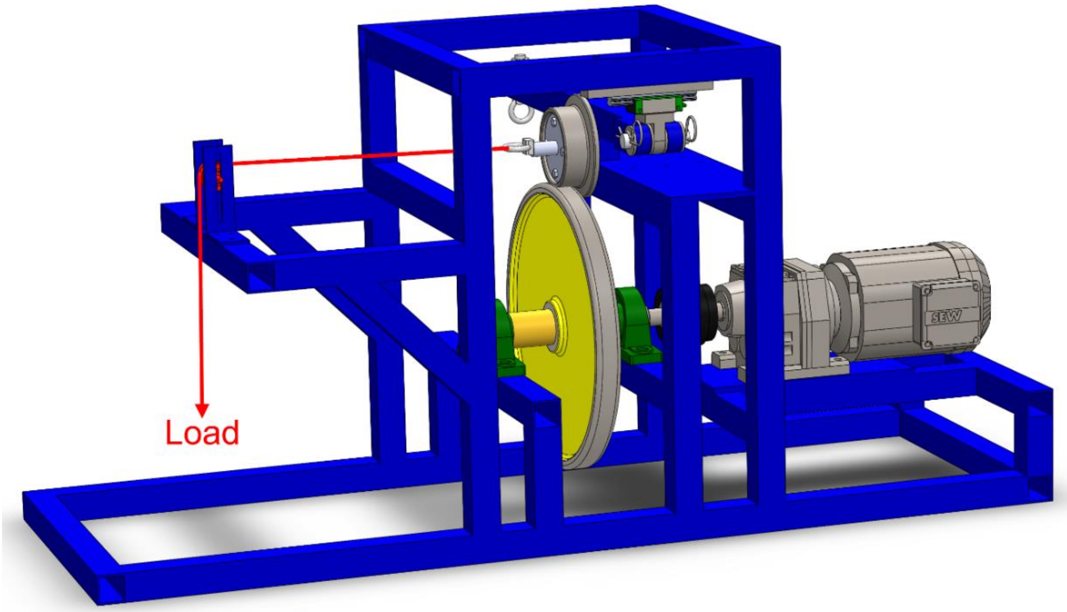


Figure 24. Track wheel axial load measurement

Figure 25 shows the results for combined radial and axial loading where an increase in axial load results in an increase in the measured friction factor of the track wheel. Despite the increase over pure radial loading, the friction increase is still within acceptable limits (≤ 0.010 for fully loaded conditions) when compared to conventional belt conveyors.

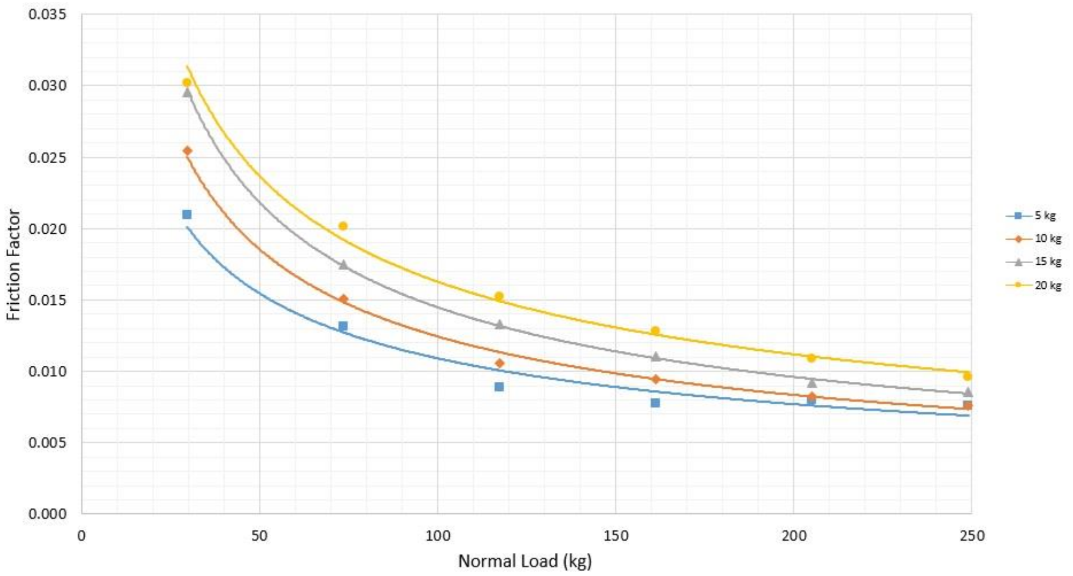


Figure 25. Track wheel friction versus axial load (Ellis [15])

5. COST COMPARISON TO TRADITIONAL BELT CONVEYORS

A detailed cost comparison between the Rail Conveyor technology and conventional belt conveyor shows significant potential for both capital and lifecycle cost savings. In this section the total cost of ownership for the Rail Conveyor system and conventional belt conveyor will be compared for the transportation of run-of-mine (ROM) coal both in-plant over a distance of 1 km and overland a distance of 10 km. Specifications for both the Rail Conveyor and belt conveyor systems for a 1 km and 10 km long systems are detailed in Table 1 and Table 2 respectively.

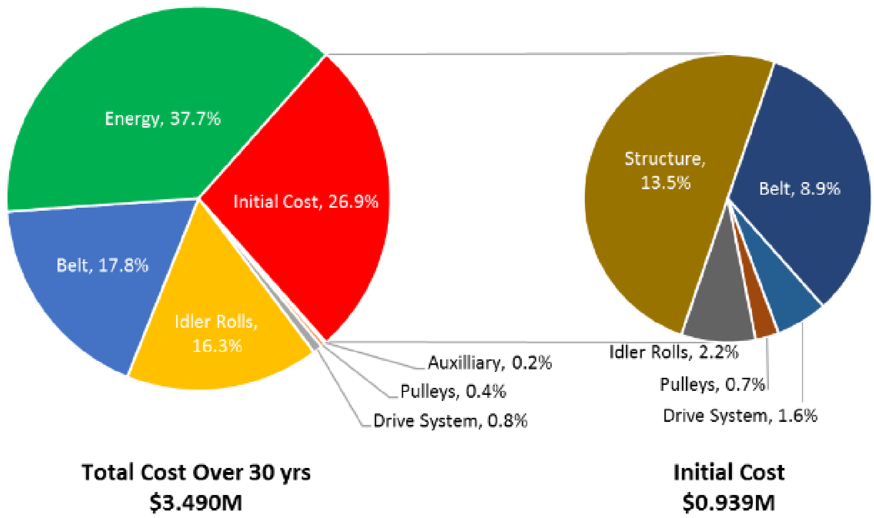
Design Specifications	Belt Conveyor	Rail Conveyor
Bulk Material	ROM Coal	
Bulk Material Density	850 kg/m^3	
Design Capacity	1000 t/hr	
Belt Speed	3.5 m/s	3.5 m/s
Belt Width	1,200 mm	1,200 mm
Horizontal Length	1,000 m	1,000 m
Lift	0 m	0 m

Table 1. 1 km Long Belt and Rail Conveyor Specifications

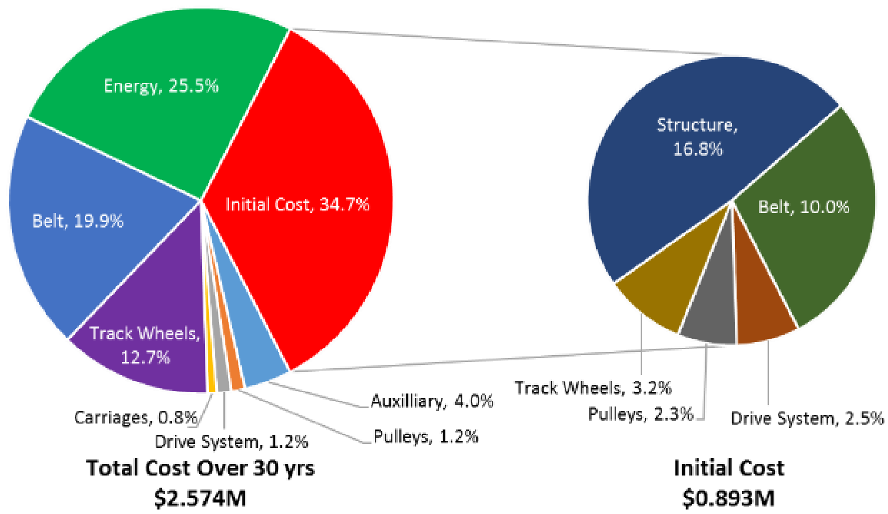
Design Specifications	Belt Conveyor	Rail Conveyor
Bulk Material	ROM Coal	
Bulk Material Density	850 kg/m^3	
Design Capacity	1000 t/hr	
Belt Speed	3.5 m/s	3.5 m/s
Belt Width	1,200 mm	1,200 mm
Horizontal Length	10,000 m	10,000 m
Lift	0 m	0 m

Table 2. 10 km Long Belt and Rail Conveyor Specifications

A full cost analysis of the Rail Conveyor system and conventional belt conveyor was undertaken based on a 30-year service life. Both the initial cost of installation and ongoing cost of maintenance were considered. The assumptions of what is included and excluded from each cost analysis is found in Figure 26 and Figure 27 for each of the respective system lengths. Assumptions include; a 30 year service life, 80% utilisation, a carry side idler roll life of 3.2 yrs (22 500 hrs), a return side idler roll life of 5.1 yrs (35 500 hrs), a track wheel life of 6 yrs (42 000 hrs), rail life of 30 yrs and a belt life of 10 yrs. The cost analysis has not considered civil or labour costs. Furthermore, energy costs have been based on 5c/kWh, although this value would be expected to change during the life of each system.



(a) Belt Conveyor

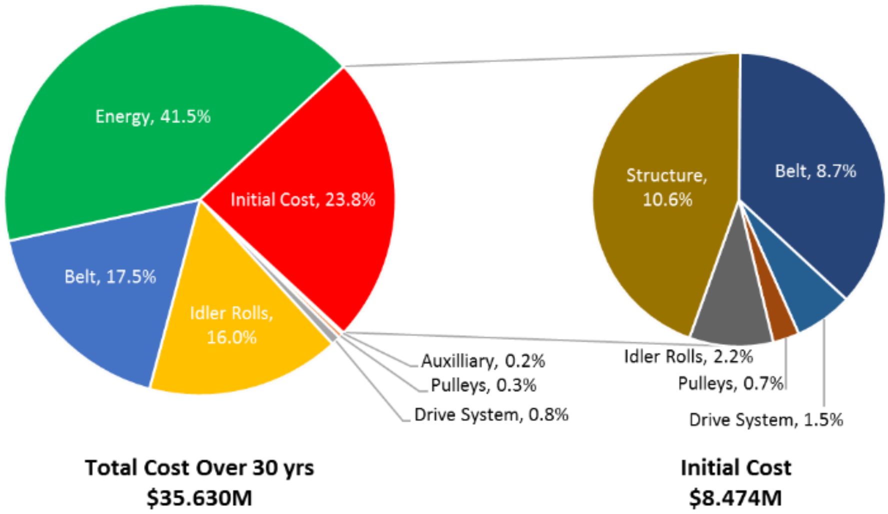


(b) Rail Conveyor

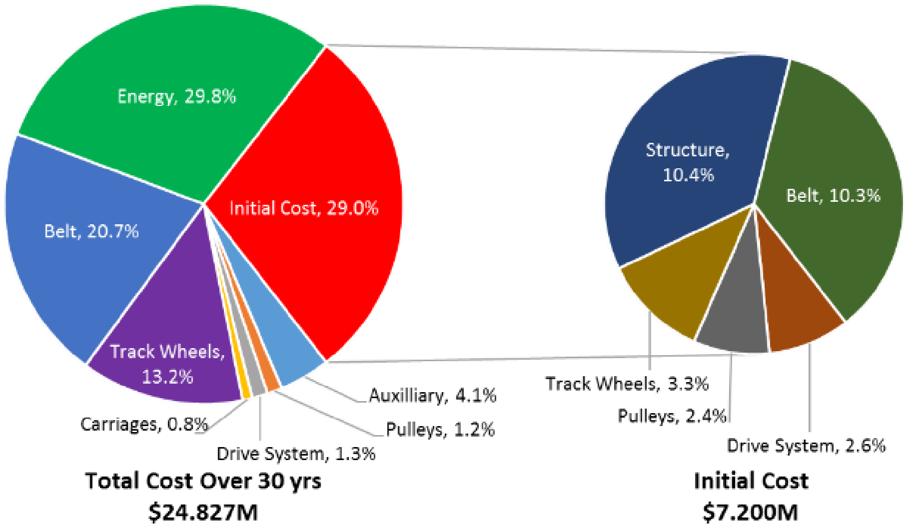
Assumptions:
(1) Costs based on a 30 year service life.
(2) Costs based on an 80% utilisation.
(3) Costs in US dollars and excludes inflation.
(4) Costs based on manufacture in China.
(5) Site construction and civil costs excluded.
(6) Labour maintenance costs excluded.
(7) Carry side idler roll life = 3.2 yrs (22 500 hrs).
(8) Return side idler roll life = 5.1 yrs (35 500 hrs).
(9) Track wheel life = 6 yrs (42 000 hrs).
(10) Rail life = 30 yrs.
(11) Belt life = 10 yrs.
(12) Energy costs based on 5^{c}/kWh.

Figure 26. Cost comparison for a 1 km long belt conveyor and Rail Conveyor system

Figure 26 provides a detailed life-cycle cost comparison for a 1 km long system transporting coal at 1000 t/hr. In addition to the 5% capital cost saving, a 26% cost saving is calculated over the 30-year life of the installation, excluding interest.



(a) Belt Conveyor



(b) Rail Conveyor

Assumptions:
(1) Costs based on a 30 year service life.
(2) Costs based on an 80% utilisation.
(3) Costs in US dollars and excludes inflation.
(4) Costs based on manufacture in China.
(5) Site construction and civil costs excluded.
(6) Labour maintenance costs excluded.
(7) Carry side idler roll life = 3.2 yrs (22 500 hrs).
(8) Return side idler roll life = 5.1 yrs (35 500 hrs).
(9) Track wheel life = 6 yrs (42 000 hrs).
(10) Rail life = 30 yrs.
(11) Belt life = 10 yrs.
(12) Energy costs based on 5^c/kWh.

Figure 27. Cost comparison for a 10 km long belt conveyor and Rail Conveyor system

Figure 27 provides a detailed life-cycle cost comparison for a 10 km long system transporting coal at 1000 t/hr. In addition to the 15% capital cost saving, a 30% cost saving is calculated over the 30-year life of the installation, excluding interest. A summary of the cost comparison and potential savings for the Rail Conveyor technology for both a 1 km and 10 km long system are summarised in Figure 28.

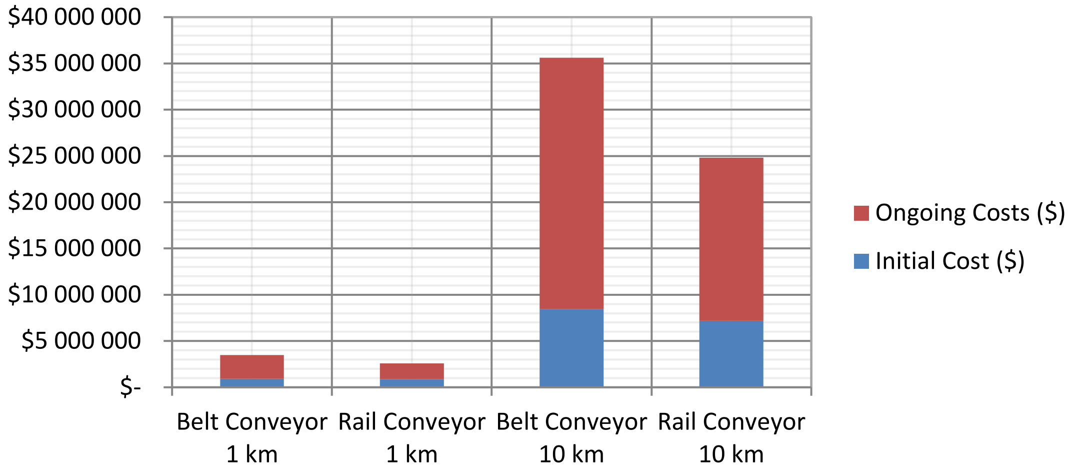


Figure 28. Cost comparison between belt conveyor and rail conveyor

The reduced cost of the Rail Conveyor technology is due to less cumulative tension because of the lower running resistances. This reduction in turn results in lower belt tensions and power, leading to lower strength belt, lighter structure, and smaller pulleys and drive units. Further cost saving are therefore predicted as the system length increases. Capital cost savings are not only dependent on the length of the system, but also the density of the bulk material being conveyed. The greater savings are achievable from bulk materials with greater bulk densities due to the ability to increase the distance between support carriages in comparison to the pitch of conventional belt conveyor idler sets. For example, in iron ore applications the maximum pitch is typically restricted to around 2 m, and while the maximum sag of the belt is one criterion for establishing the pitch between idler sets, often for long belt conveyors the governing factor is the need to limit the stress in the bottom cover of the belt when in contact with the idler rolls. Unlike conventional belt conveyors that support the belt on idler rolls, the Rail Conveyor carriages can be designed to support the belt over a greater surface area thus reducing the contact pressure, enabling the distance between support carriages to be larger than the pitch between conventional conveyor idler rolls, and in turn reducing the capital cost of the system.

6. CONCLUSIONS

This paper presented a new technology for the continuous transportation of bulk materials. The Rail Conveyor represents a significant and novel deviation from traditional bulk material transportation systems. Initial tests have demonstrated significant energy savings due to the elimination of traditional running resistances of belt conveyors. These energy savings are coupled with the ability to transport over significantly longer distances due to a reduction in cumulative belt tension. The Rail Conveyor technology also shows great promise from a cost perspective, with initial costing indicating significant cost advantages over conventional belt conveyors, particularly with increasing transportation distance.

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