TECHNOLOGY REVIEW AND COST ANALYSIS OF LIGHT GAUGE RAIL-BASED BULK MATERIAL HANDLING SYSTEMS

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ABSTRACT

The need for energy efficient long distance high capacity bulk material transportation has seen the development of a range of new light gauge rail-based transportation systems. These include both continuous and batch systems that can provide significant CAPEX and OPEX savings due to energy benefits attributed to lower rolling friction than traditional belt conveyors.

The aim of this paper is twofold. Firstly, a technology review of new light gauge rail based systems will be presented to provide a current state-of-the-art. Rail and track considerations will be discussed in relation to light gauge rail. Secondly, a detailed economic comparison between a continuous rail-running belt conveyor and traditional belt conveyor will be presented for a range of iron ore and coal case studies in Australia, Canada and South Africa. The economic study will identify particular characteristics of rail-running conveyors that have the greatest impact on both CAPEX and OPEX.

1. INTRODUCTION

As new mineral and ore deposits are mined further from existing processing plants, power stations and ports, the demand for transporting bulk materials over longer distances is increasing. With this progressive increase in length and capacity the need for more energy efficient continuous conveying systems is needed, and despite recent advances in low rolling resistance bottom cover compounds, the motion losses of belt conveyors effectively limit their operational length and cost effectiveness. The primary limitation of conventional belt conveyors is the interaction between the rubber covered belt and idler rolls, meaning they will never match the efficiency of traditional railway with steel wheels running on steel tracks.

With these objectives and limitations in mind, rail based bulk material transportation systems show tremendous promise. In particular, where large capacity long distance transportation is needed, tightly curved routes are required, and where relocation or re-routing flexibility is desired, rail-based transportation methods can have significant advantages. For example, in the case of long distance high capacity bulk material transportation, rail-based systems have significant benefits due to lower rolling resistance when compared to conventional belt conveyors due to the elimination of traditional motion resistances such as indentation rolling resistance and belt and bulk material flexure resistance.

Wheels and rail are used across a wide range of bulk material transportation and handling systems due to their low rolling resistance. The most common application is trains, while others include; haulage skips, large mobile material handling equipment, such as stackers and reclaimers, shuttle conveyors, trippers and conveyor take-up trolleys. More recently the benefits of wheels and track have been exploited in a number of light gauge rail bulk material handling applications, including both batch and continuous applications.

While light gauge rail systems have been used for hundreds of years in a range of mining and quarrying industries, new approaches have focused on efficient distribution of drive power and new discharge methods. Furthermore, new continuous rail-conveyors have also been developed to take advantage of the low rolling friction in combination with the added advantages of continuous transportation.

An important and often overlooked characteristic of rail-based systems, is that rolling friction is essentially independent of operating temperature. While the viscosity of grease used in rolling element bearings and seals is temperature dependent, aviation greases can be used in low temperature applications to minimise variation, meaning demand power between summer and winter varies very little.

This paper will first review some of the newer rail-based bulk material transportation systems, including both batch and continuous transportation methods. Specific details of light gauge rail and wheel considerations will be discussed, with some commonality drawn between traditional railway engineering, while other aspects such as rolling friction are particular to light duty applications. Finally, the paper will present a series of case studies for typical long overland conveying applications, where a continuous rail-running conveyor is compared and found to provide significant CAPEX and OPEX savings. These savings are achieved for a variety of reasons, but clear trends can be identified across all case studies examined.

2. RAIL BASED BULK MATERIAL TRANSPORTATION SYSTEMS

When considering bulk material transportation systems these can be considered batch (or discontinuous) or continuous systems. Traditional batch rail-based systems include heavy haulage trains and skips, and more recently light gauge systems such as the Rail-Veyor [1] and Autonomous Rail Conveyor [2] systems. Furthermore, a continuous rail-based system known as the Rail Conveyor has also been developed [3]. For the purpose of this paper each of these light gauge rail systems will be discussed. The benefit of light gauge rail over heavy gauge rail is reduced civil costs due to less load per unit length, meaning there is often no need for ballast, and sleeper spacing can be increased significantly over traditional rail.

2.1 RAIL-VEYOR

The Rail-Veyor is a batch transportation system consisting of a series of coupled carriages driven at regular intervals by rubber tyres in contact with the outer sides of the carriages. Drive motors are positioned along the length of the system at a distance less than the length of the individual trains (see Figure 1). The carriages are directed over a vertical turnover wheel at the discharge point, allowing the bulk material to slide out of the carriages into a discharge bin as shown in Figure 2.

Figure 1. Rail-Veyor drive system (McCall, 2016)

Figure 2. Rail-Veyor discharge system (McCall, 2016)

2.2 AUTONOMOUS RAIL CONVEYOR

The Autonomous Rail Conveyor (ARC) system is a series of interconnected bogies, covered with a conventional conveyor belt to support the load, running on relocatable light rail. Each bogey has two axles, each driven by integrated variable speed geared motor and brake systems, and are connected to adjacent bogeys by specialised couplers. Power is provided by a generator (located in a dedicated bogey) and "daisy chain" plug in cables [2].

Loading is achieved by feeding the ARC from a perpendicularly oriented apron feeder, whilst material off-loading is accomplished by a "twist dump" operation in which the belt is twisted through an angle of 50° below the horizontal, causing material to flow from the belt into a receiving conveyor. Figures 3 and 4 show the twist-dump system.

The ARC system can run multiple trains over any distance, although benefits are reported to be more significant in distances of over 2 km. The ARC system is still at the prototype stage but does show promise as it eliminates the need to supply power to drive stations continuously along the length of the system in addition to the innovative discharge system.

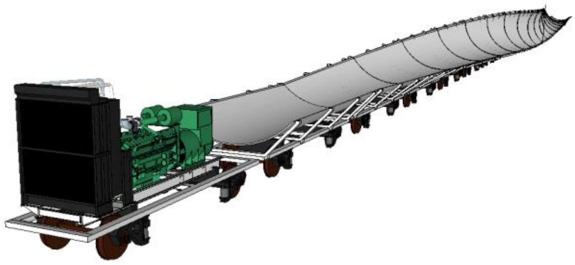


Figure 3. ARC twist-dump system (Graham, 2017)

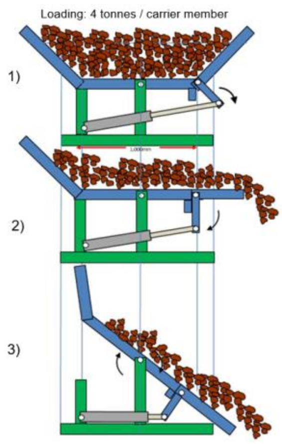


Figure 4. ARC load bed progressively twisted through to 50° to dump material (Graham, 2017)

2.3 RAIL CONVEYOR

The Rail Conveyor is a continuous rail-based bulk material transportation system that 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 as shown in Figure 5. 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 [3,4,5].

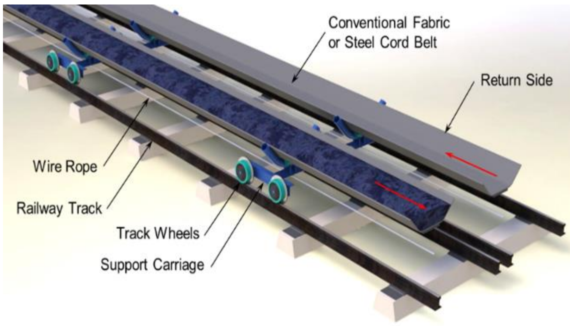


Figure 5. Rail Conveyor concept (Wheeler et al., 2017).

Figure 6. Demonstration system (Wheeler et al., 2017)

The continuous nature of the Rail Conveyor system results in a considerably lower load per unit length than discontinuous systems since the load is distributed over the entire length of the system. The load is discharged at a head pulley like a conventional belt conveyor. Figure 6 shows a demonstration system operating in China where the carriages are recirculated via vertical turnaround wheels at the head and tail end of the conveyor [4,5].

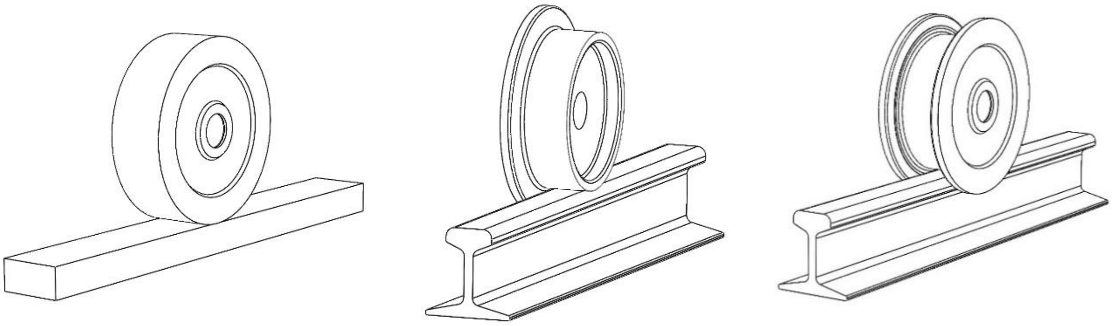
3. RAIL AND TRACK WHEEL CONSIDERATIONS

All rail-based bulk material transport systems share the common infrastructure of track and wheels. As a result a number of important considerations will now be discussed, including: typical wheels and track, traditional wheel sets versus Independently Rotating Wheels (IRW), guidance mechanics and rolling friction.

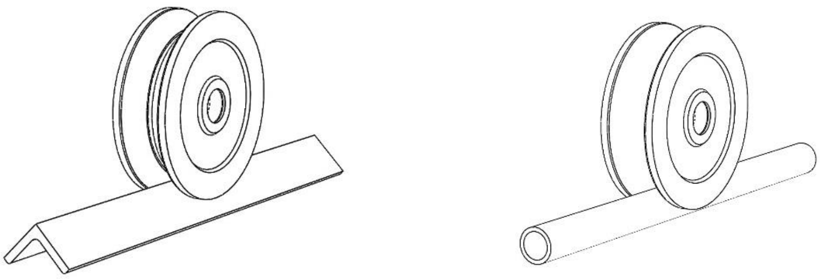
3.1 WHEELS AND TRACK

Track wheels are typically cast or forged steel heat-treated to a specific hardness, although nylon and polyurethane can be used for applications operating under light loads, such as rail running conveyors. For self-guidance purposes traditional rail wheels are generally tapered and fixed to a common axle to form a wheelset. Rail wheels have a flange on one side to prevent wheel climb and possible derailment when the limits of the geometry-based alignment are reached.

There are variety of wheel and track types and configurations with varying axial constraint. Track wheel types include plain roller, single and double flange track wheels, and V and U grooved wheels. The tracks are typically specific to the track wheel as shown in Figure 7. Grooved track wheels are used in applications requiring improved alignment accuracy, but do exhibit greater sliding friction, leading to increased friction and higher wear [6].



(a) Plain roller track wheel (b) Single flange track wheel (c) Double flange
track wheel



(d) V groove track wheel (e) U groove track wheel

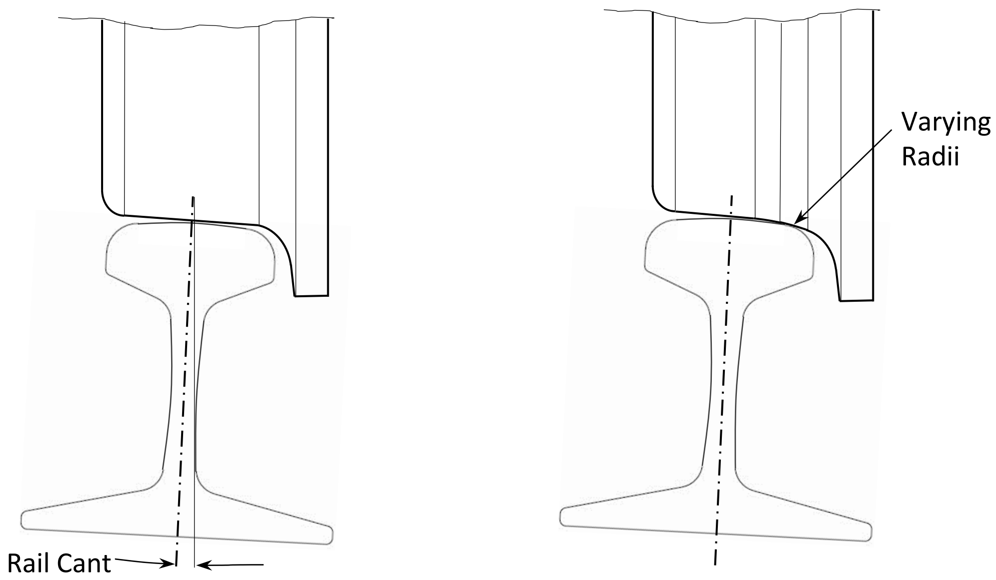
Figure 7. Types of track wheels and track (Katterfeld et al., 2019)

3.2 GUIDANCE OF CONVENTIONAL WHEELSETS AND INDEPENDENTLY ROTATING WHEELS

The combination of wheels rigidly fixed to an axle is known as a wheelset. Semi-conical wheels (see Figure 8 (a)) are fixed to an axle, resulting in both wheels turning at the same angular velocity. The guidance of a wheelset traveling along a straight track occurs, since as the wheelset is displaced axially, the radius at the point of contact is different from one wheel to the other due to the semi-conical profile. During this process, one wheel becomes the driving wheel and the other becomes the braking wheel, until the symmetrically opposite condition occurs. This repeated axial movement is known as hunting and can result in uneven rail wear.

This same guidance mechanism guides wheelsets around curves, as the requirement for different linear speeds between the inside and outside rail are matched due to the varying diameter of the semi-conical wheel, thus preventing the wheelset from rubbing on the flanges while traveling around the curve.

The term Independently Rotating Wheels (IRW) refers to wheels that do not necessarily have the same angular velocity. They are often used in trams where smaller radii curves are required as a traditional wheelset will generate excessive slip, and therefore wear. In the case of IRWs guidance is achieved fully via the wheel geometry. Wheels exhibit an increasing gradient from the outer edge to the wheel flange often via a series of radii as shown in Figure 8 (b).



(a) Conical rail wheel (b) Independently rotating wheel profile

Figure 8. Rail wheel profiles

Figure 9 shows a pair of IRW with a lateral offset and the resulting geometrical profile force, Sy, acting on the left and right wheels. These forces are opposite in direction and considerably different in magnitude, resulting in a centring effect that is a function of the lateral offset. N is the normal force. In this case the guidance mechanism is practically free from wear [7].

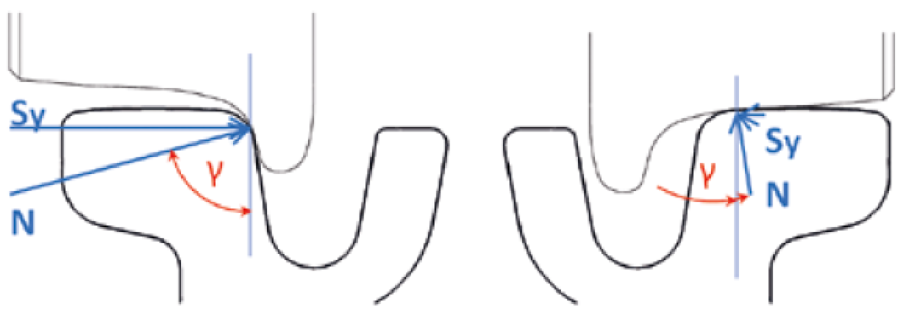


Figure 9. Balance of forces on laterally offset IRWs (Erlangen, 2016)

Rails are typically hot rolled steel. The rail head profile is designed to minimize wear while the rail foot is designed to suit the supporting structure. Tracks are typically canted to direct the line of force through the web to the foot as shown in Figure 8.

4. ROLLING RESISTANCE

The rolling resistance of a track wheel is comprised of a number of components. These components typically are:

- Bearing and lubricant resistance
- Seal resistance
- Rolling and sliding friction due to the interaction of the wheel and track
- Energy loss due to track interaction with supporting structure

Rolling resistance is the force resisting the motion of the wheel as it rolls along the track. The resistance occurs since the energy of deformation is not fully recovered when the pressure is released. This results in hysteresis losses and an asymmetric pressure distribution in the contact zone that generates a moment that acts to retard the rolling motion. Additionally, rolling resistance occurs due to slip between the wheel and the track that dissipates energy. Like sliding friction, rolling resistance is often expressed as a coefficient times the normal force [6].

Figure 10 shows a track wheel rolling on track to the left at constant speed. N is the normal force, F is the pull force, r is the wheel radius and R is the resultant force from non-uniform pressure at the wheel-track interface. The contact pressure is shown, and is greater towards the front of the wheel due to hysteresis. Note in this simplified case the torque due to the bearing and seal friction, and the energy loss due to the track interaction with the supporting structure, are neglected.

The rolling resistance force, F, may be expressed as:

$$F = C_{rr}N \tag{1}$$

where: Crr = rolling resistance coefficient
N = normal force

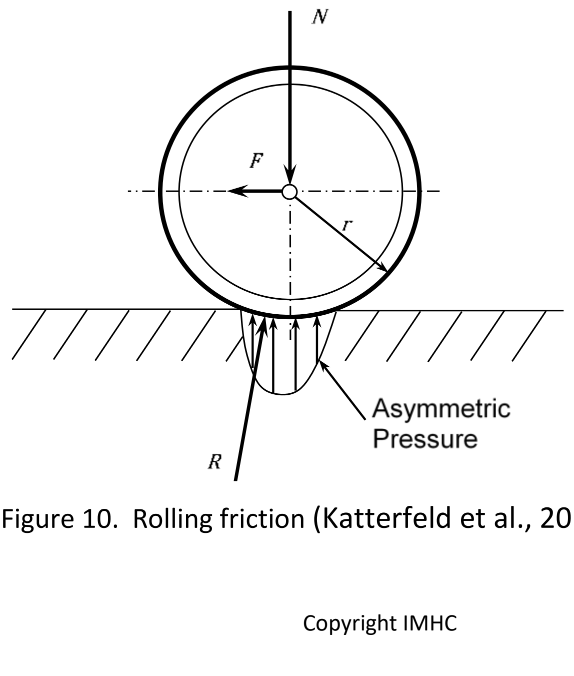


Figure 10. Rolling friction (Katterfeld et al., 2019)

Table 1 shows typical rolling resistance coefficients for a number of track wheel applications, with truck and passenger vehicle tyres included for comparison.

Table 1. Rolling friction coefficients

Rolling friction coefficient, Crr	Description
0.0010 to 0.0024 (Hay [8])	Railroad steel wheel on steel rail
0.0019 to 0.0065 (Hersey [9])	Mine car cast iron wheels on steel rail
0.005	Dirty tram rails with straights and curves
0.0045 to 0.008	Large truck tires
0.010 to 0.015 (Gillespie [10])	Passenger car tires on concrete

More specifically Szklarski [11] provides a comprehensive list of friction values dependent on wheel and rail condition in the case of underground haulage systems. The table is repeated as Table 2.

Table 2. Rolling friction coefficients between rail and wheel (Szklarski, 1969)

Rolling friction coefficient, Crr	Condition
0.002	Wheels very carefully machined, state of rails excellent
0.003	Wheels very carefully machined, state of rails good
0.005 to 0.007	Wheels carefully machined, state of rails good
0.010	Wheels average, state of rails average
0.0125	Wheels poor (not machined), state of rails poor

Furthermore, the authors have undertaken an extensive study into lightly loaded track wheels for the purpose of predicting rolling resistance. This research required the manufacture of purpose built test facilities to measure the rolling resistance and sealing performance for a range of track wheel diameters, materials of construction and seals. Figure 11 shows a typical track wheel configuration where a single neoprene lip seal is used to minimise resistance and potential source of contaminant ingress. Figure 12 shows the water ingress test facility for evaluating sealing performance.

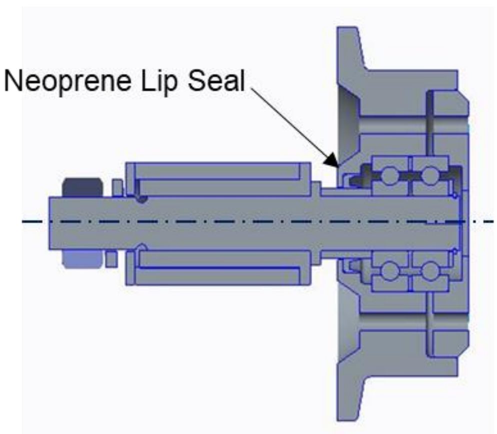
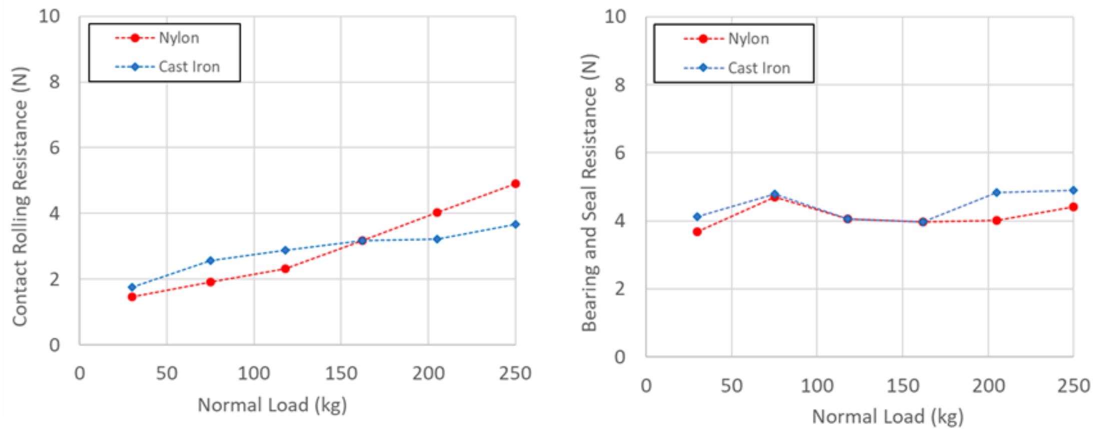


Figure 11. Typical track wheel

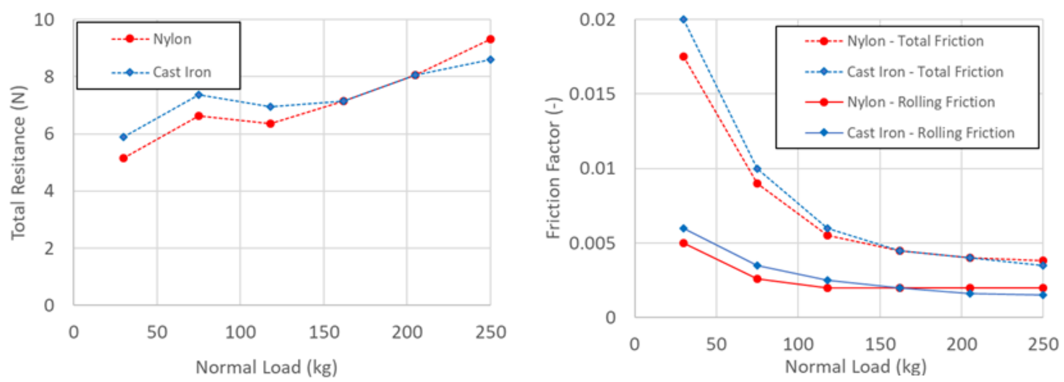
Figure 12. Water ingress seal test

Figure 13 (a) shows the measured rolling contact force as a function of applied load for both Nylon and Cast Iron track wheels of 140mm diameter. Similarly, for the same wheels the bearing and seal resistance force is shown in Figure 13 (b). Figure 14 (a) shows the sum of the rolling contact force and bearing and seal resistance forces for the same wheels. Similarly, Figure 14 (b) shows the rolling contact friction only, in addition to the total rolling resistance coefficient that considers the bearing and seals.



(a) Rolling contact resistance of wheels (b) Rolling friction factor, Crr

Figure 13. Individual resistances versus load for Nylon and Cast Iron wheels (Ellis, 2016)



(a) Total rolling resistance force (b) Rolling friction factor, Crr

Figure 14. Total rolling resistance and friction coefficient for Nylon and Cast Iron wheels (Ellis, 2016)

The measured rolling friction coefficients compare favourably to those in Table 1 and Table 2. Of considerable note is the similarity in rolling resistance coefficient of both Nylon and Cast Iron, with selection being determined by cost, weight and wear properties based on the particular operating environment. Additionally, the use of nylon wheels also results in the benefit of noise reduction capabilities. Furthermore, there is a notable reduction in the rolling resistance coefficient with load as the effect of the seal and bearing resistance diminishes with increasing load. This effect occurs since the bearing and seal resistance is essentially independent of load under these load cases.

5. CASE STUDIES – RAIL VS CONVENTIONAL

The CAPEX savings from the Rail Conveyor technology flow from a range of characteristics. The particulars of each conveyor system determine which characteristics will have the greatest impact on CAPEX. In studies to date it was seen that the CAPEX reductions emerge from the following areas, roughly in order of contribution [13]:

- Lower belt strength.
- Reduced number of flights and transfer points.
- Lower installed power at each drive station.
- Smaller electrical infrastructure.
- Narrower belt and supporting structures.
- For incline conveyors, lower belt strengths and drive torques thanks to higher belt speeds.
- Less elevated structure and cut/fill excavation.
- Lower erection costs, thanks to smaller and lighter equipment and structures.
- Reduced outlay for capital spares.

Similarly, OPEX savings arise from a range of the technology's attributes. Although OPEX savings take more effort to quantify, studies point to the following rough hierarchy of continuing OPEX reductions:

- Much lower power consumption, with even sharper improvements in cold climates.
- Power generation typically twice as high for regenerative conveyors.
- Idler failure costs and related safety issues largely eliminated.
- Chute maintenance and belt damage eliminated wherever a transfer point is eliminated.
- Carry-back and build-up costs eliminated outside of the head and tail areas, as are costs due to belt flap, mistracking, frozen idlers, and bottom-cover wear.

To quantify the primary CAPEX and OPEX differences, the Denver office of thyssenkrupp Industrial Solutions (USA) developed case studies for a 15 km Western Australian (Pilbara) iron ore conveyor and both 21 and 51 km South African coal conveyors. The Denver office specialises in long overland and heavy duty conveyors. For these case studies, a cost-estimating software tool developed in collaboration with Overland Conveyor Company was used.

Some of the main design choices for building the CEMA [14] models in Belt Analyst for the "base case" conventional trough conveyors included:

- A low-friction approach, aiming for the kind of "best-in-class" friction levels attainable when component and erection quality are selected for low friction and closely controlled, and where lower operating costs can be used to justify higher up-front expenditure.
- A minimum belt factor of safety of 5.3 during cool-season operation.
- Installed drive capacity was selected based on the minimum operating temperature that would occur, rather than partial-load conditions.

- A belt speed of 6.5m/s was used for all versions, including the Rail Conveyor cases.

After creating and running the conventional models, the Rail Conveyor versions were built from the same files. A conservative all-in carriage friction value of 0.005 was used to calculate the friction-related tension for the particular belt selection, carriage weight and material load. Then friction factors in the CEMA [14] components were manually adjusted to give the correct carry and return-side tensions due to carriage friction.

For the Rail-Conveyor version, narrower belt widths were selected because the moving carriages can support the belt in a steep trough without any idler-load or friction penalty.

The analysis showed that the weight of Rail Conveyor carriages in a system is perhaps 20% to 30% less than the weight of the idlers and idler frames that the carriages replace. It is worth noting that although the carriage spacing on the carry side can be significantly greater than conventional idler spacing (3 m was used in the case studies), the same spacing applies to the return side. Given these relatively small differences, the case studies made the approximation that idler and carriage CAPEX costs are the same.

These case studies only quantified the CAPEX savings flowing from lower friction, without considering changes to route or the number of flights. The OPEX studies were similarly limited to reductions in power, consumables and idler maintenance costs. For idler-related costs, the comparison assumed that replacement rates for carriage wheels would be equivalent to those for idlers, but that the number of on-demand maintenance crews could be reduced by one for the Rail Conveyor system.

An estimate of construction costs was included as part of the cost calculation because – in most cases – construction costs are closely indexed to the value (i.e. extent, weight and power) of the supplied components. For purposes of the calculation, construction costs were taken as 50% of the equipment supply price, although some references for the Pilbara report that construction costs run to 100% of the equipment supply.

5.1 IRON ORE – 15 KM LONG OVERLAND CONVEYOR

The 15 km iron ore conveyor used as an example in the first set of case studies falls into the class of long overlands, considered when ore from a new mining area must be hauled to distant existing processing or load-out facilities. Details of the particular topography, tonnage and route were recently published in Western Australian government permitting documents, and these served as the source for Belt Analyst models. The conveyor horizontal length of about 15 km includes a gradual horizontal curve of ninety degrees, and a slightly downhill path that tends to offset the effects of friction along the beltline. To give a sense of how tonnage influences the resulting costs, cases were run for three different tonnages; namely 4,000, 7,500 and 12,000 mtph (metric tph) with the specifications shown in Table 3.

Table 3. System specifications for 15 km long iron ore conveyor for variable throughputs

	Units	Belt Conveyor / Rail Conveyor					
Design Capacity	mtph	4,000		7,500		12,000	
System	-	Belt	Rail	Belt	Rail	Belt	Rail
Warm Season Temp.	°C	30	30	30	30	30	30
Cool Season Temp. (For Belt Strength)	°C	8	8	8	8	8	8
Coldest Temp. (For Installed Power)	°C	0	0	0	0	0	0
Lift	m	50	50	50	50	50	50
Belt, ST Rating	-	2500	1400	2800	1800	2800	2000
Belt Width	mm	1050	900	1400	1200	1800	1600
DIN f Equivalent - Warm Season	-	0.012	0.005	0.011	0.005	0.010	0.005
DIN f Equivalent - Cool Season	-	0.013	0.005	0.012	0.005	0.011	0.005
DIN f Equivalent - Coldest Operating Temp., High Drag	-	0.015	0.005	0.014	0.005	0.013	0.005
Total Installed Power	kW	5,000	1,200	7,000	2,000	9,000	3,000
Head Drives	-	3 x 1,250	2 x 600	3 x 1,750	2 x 1,000	3 x 2,250	3 x 1,000
Tail Drives	-	1 x 1,250	0	1 x 1,750	0	1 x 2,250	0
Power at Design Tonnage, Warm Season	kW	2,988	946	4,524	1,604	6,148	2,394
Power at Design Tonnage, Cool Season	kW	3,375	946	5,188	1,604	6,996	1,560

A summary of a Pilbara Owner's as-constructed CAPEX is shown in Figure 15 and a summary of the OPEX is shown in Figure 16. All figures are shown in $US 1,000's.

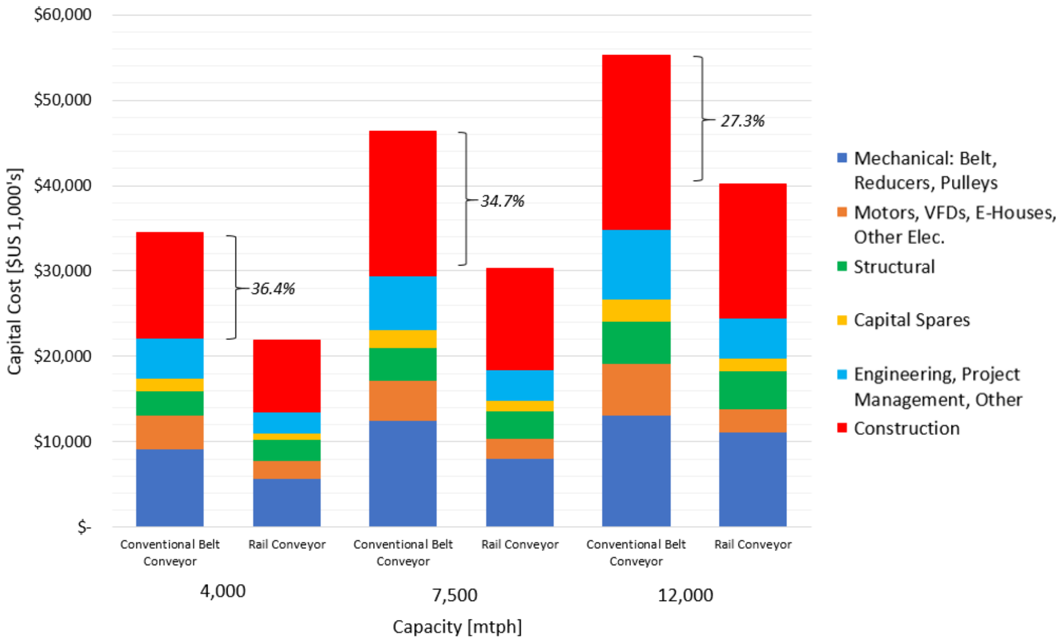


Figure 15. CAPEX vs capacity for Rail Conveyor system and conventional belt conveyor - Iron Ore

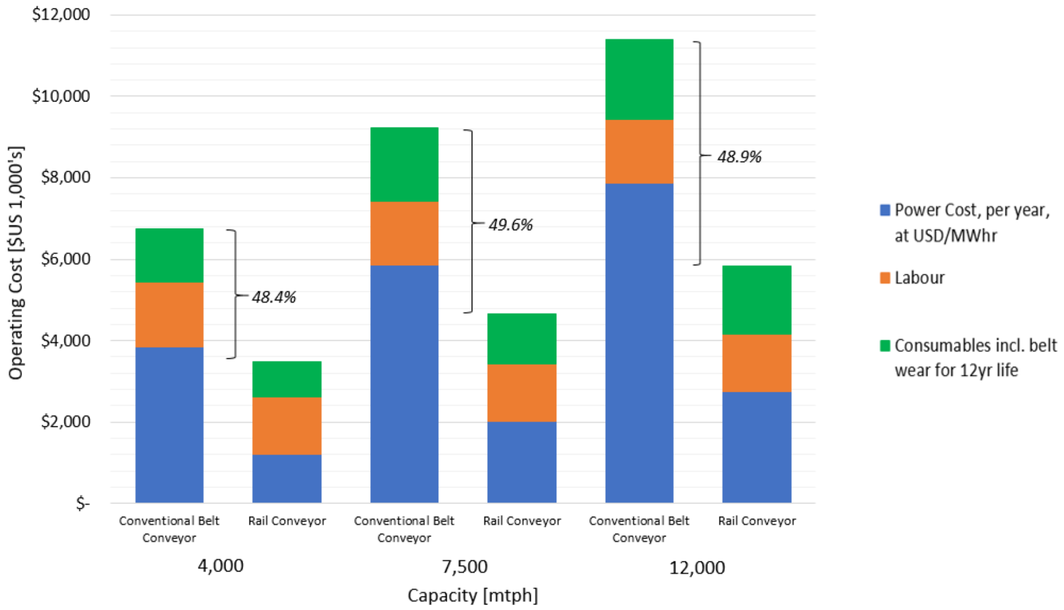


Figure 16. OPEX vs capacity for Rail Conveyor system and conventional belt conveyor - Iron Ore

The calculated cost advantages for these Rail Conveyor cases turned out to be substantially larger than predicted by studies done by thyssenkrupp Industrial Solutions (USA) several years ago. These increased savings are mostly due to the increasing cost associated with the electrical portion of a conveyor system, including motors, VFDs, transformers, switchgear etc. The scale of the savings seen in these three case studies probably represents the lower end of the range that would be seen for high-tonnage iron-ore conveyor systems. For shorter conveyors carrying lower tonnages, the savings will be smaller – if just the same aspects are considered.

The 15 km Pilbara conveyor was also analysed for a very cold climate – such as Canada – where belt indentation at cold temperatures becomes a dominant factor on long overland conveyors. In such climates, the very high power needed to ensure that the conveyor will run during the coldest operating conditions leads to much higher CAPEX than the Rail Conveyor version, which uses essentially the same power regardless of temperature. Low-temperature grease is assumed for all cases. However, because power costs are relatively low in Canada, the OPEX differences are moderate when mainly considering power and labour. By contrast, for high-altitude Andean conditions where power can be expensive, the Rail Conveyor designs will offer compelling savings in both CAPEX and OPEX. The results of the climate case studies are summarized in Table 4 and Figures 17 and 18.

Table 4. System specifications for 15 km long iron ore conveyor for different locations (temperature)

	Units	Belt Conveyor / Rail Conveyor			
Location	-	Pilbara		Canada	
Design Capacity	mtph	7,500		7,500	
System	-	Belt	Rail	Belt	Rail
Warm Season Temp.	°C	30	30	15	15
Cool Season Temp. (For Belt Strength)	°C	8	8	-20	-20
Coldest Temp. (For Installed Power)	°C	0	0	-30	-30
Lift	m	50	50	50	50
Belt, ST Rating	-	2800	1800	4000	1800
Belt Width	mm	1400	1200	1400	1200
DIN f Equivalent - Warm Season	-	0.011	0.005	0.012	0.005
DIN f Equivalent - Cool Season	-	0.012	0.005	0.016	0.005
DIN f Equivalent - Coldest Operating Temp., High Drag	-	0.014	0.005	0.022	0.005
Total Installed Power	kW	7,000	2,000	11,000	2,000
Head Drives	-	3 x 1,750	2 x 1,000	3 x 2,750	2 x 1,000
Tail Drives	-	1 x 1,750	0	1 x 2,750	0
Power at Design Tonnage, Warm Season	kW	4,524	1,604	5,116	1,604
Power at Design Tonnage, Cool Season	kW	5,188	1,604	7,278	1,604

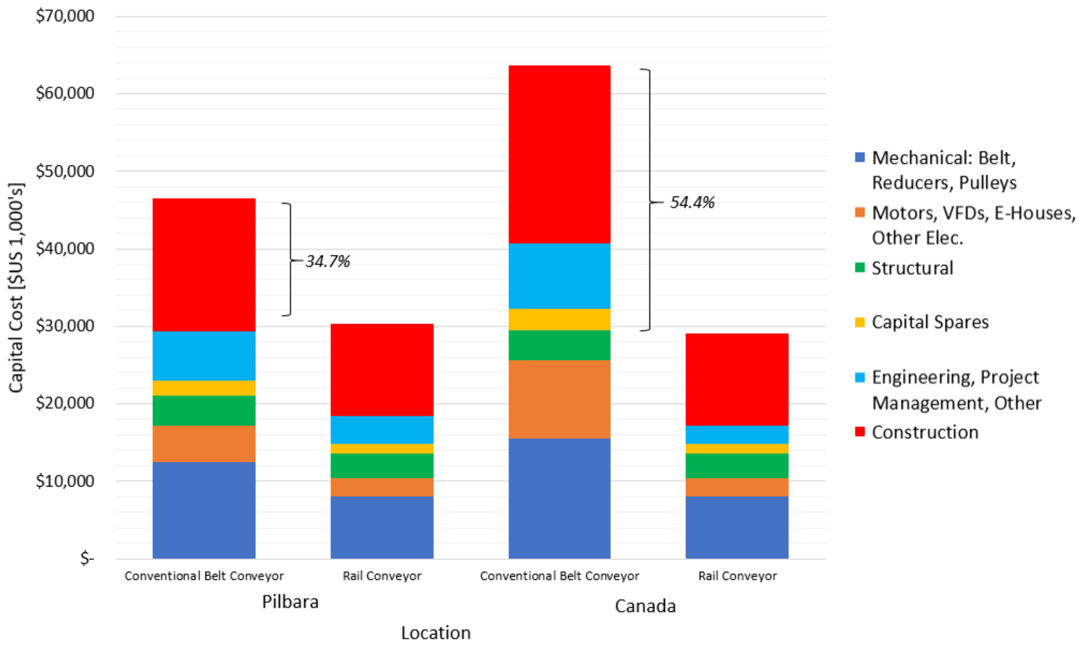


Figure 17. CAPEX vs location (temperature) for Rail Conveyor system and conventional belt conveyor - Iron Ore

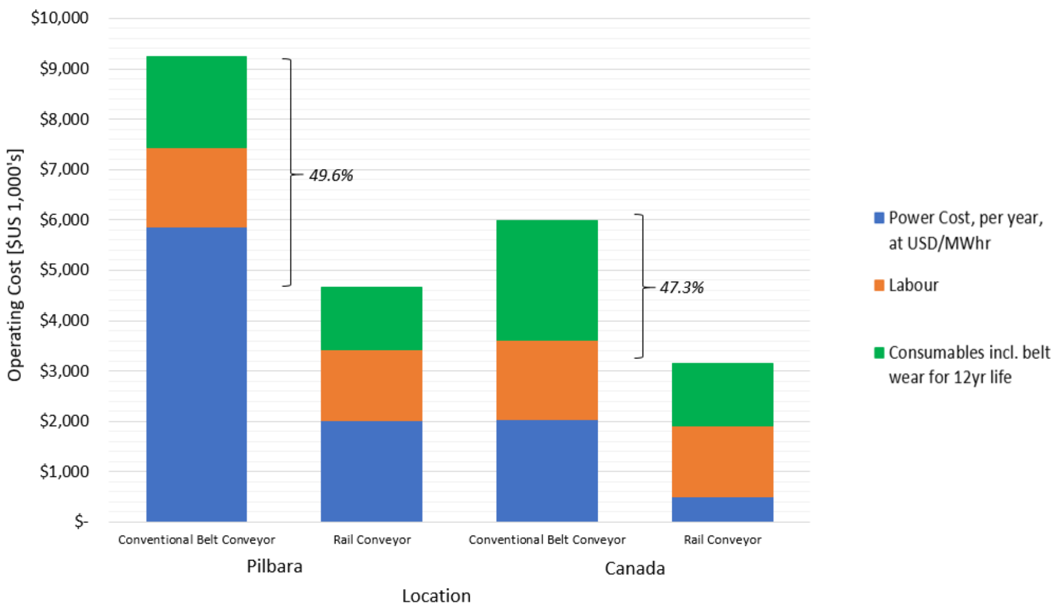


Figure 18. OPEX vs location (temperature) for Rail Conveyor system and conventional belt conveyor - Iron Ore

5.2 COAL – 21 KM LONG OVERLAND CONVEYOR

A third set of cases examined a 21 km coal-carrying conveyor route in South Africa, at tonnages of 1500 mtph, 3000 mtph and 5000 mtph. The conveyor alignment included a small net elevation gain of 40 m. The range of operating temperatures were taken as 30 ^{o} C for the warm season, and 8 ^{o} C for the cool periods that determine selection of belt fatigue strength. Table 5 shows the specifications for the 21 km long coal conveyor for variable throughputs.

Table 5. System specifications for 21 km long South African coal conveyor for variable throughputs

	Units	Belt Conveyor / Rail Conveyor					
Design Capacity	mtph	1,500		3,000		5,000	
System	-	Belt	Rail	Belt	Rail	Belt	Rail
Warm Season Temp.	°C	30	30	30	30	30	30
Cool Season Temp. (For Belt Strength)	°C	8	8	8	8	8	8
Coldest Temp. (For Installed Power)	°C	0	0	0	0	0	0
Lift	m	40	40	40	40	40	40
Belt, ST Rating	-	2000	1120	2500	1400	2500	1600
Belt Width	mm	1400	900	1400	1200	1800	1600
DIN f Equivalent - Warm Season	-	0.010	0.005	0.010	0.005	0.008	0.005
DIN f Equivalent - Cool Season	-	0.011	0.005	0.013	0.005	0.009	0.005
DIN f Equivalent - Coldest Operating Temp., High Drag	-	0.013	0.005	0.013	0.005	0.010	0.005
Total Installed Power	kW	3,200	1,400	6,000	2,400	7,000	4,000
Head Drives	-	3 x 800	1 x 700	3 x 1,500	2 x 800	3 x 1,750	3 x 1,000
Tail Drives	-	1 x 800	1 x 700	1 x 1,500	1 x 800	1 x 1,750	1 x 1,000
Power at Design Tonnage, Warm Season	kW	2,355	1,118	4,200	2,043	5,008	3,180
Power at Design Tonnage, Cool Season	kW	2,624	1,118	4,693	2,043	5,476	3,180

The low material density and warm operating temperatures applicable to these conveyors allow them to achieve the highest efficiency levels attainable from conventional trough conveyors. For example, in the 5000 mtph case, the predicted DIN f equivalent was a “best in class” value of about 0.008. One might expect that with this extremely low friction level, the rail-running versions would offer only modest advantages over conventional trough conveyors in these studies, where the all-in friction value of 0.005 used in the rail-running calculations is at the high end of the expected range.

There are also other factors that would tend to make the costs for conventional and rail-running versions converge for this set of overland coal conveyor cases. These include maintenance labour rates that were chosen in the model to be moderate at US$40 / hr (vs. $80 for the Pilbara), and electricity costs at US$100 / MWhr.

The results for these cases are summarized in Figures 19 and 20. The results illustrate that for long overland conveyors, the lower frictional losses of rail-running conveyors provide very attractive CAPEX and OPEX benefits, even without taking into account other savings that flow from the Rail Conveyor's attributes.

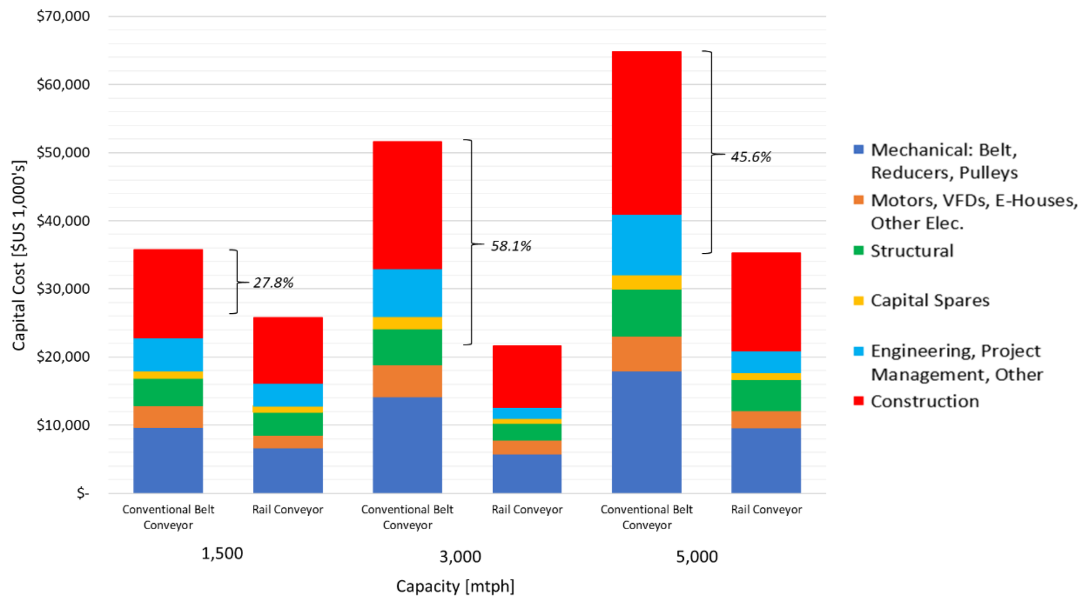


Figure 19. CAPEX vs capacity for Rail Conveyor system and conventional belt conveyor - Coal

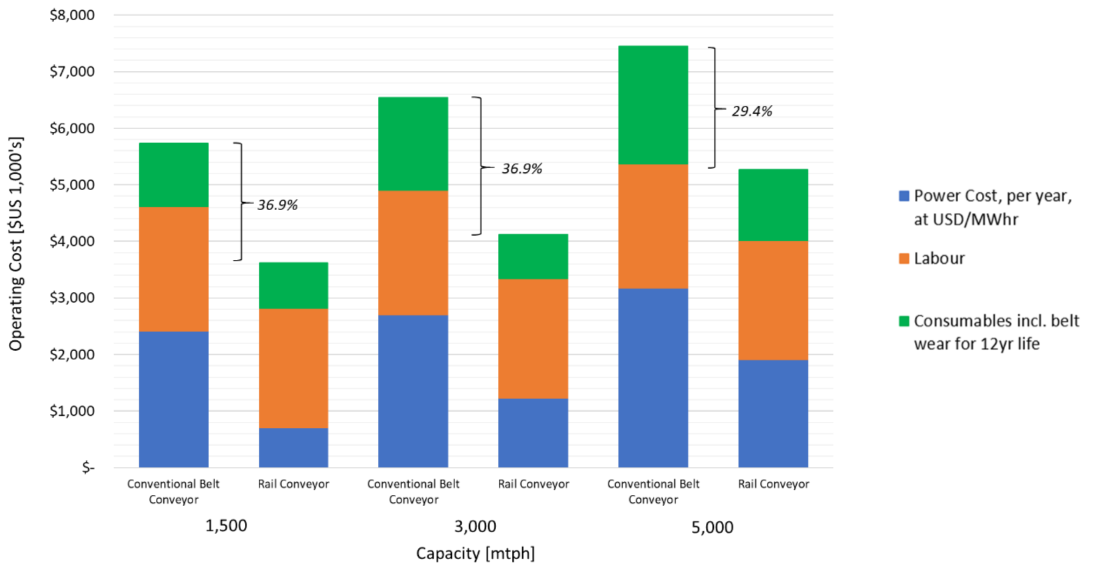


Figure 20. OPEX vs capacity for Rail Conveyor system and conventional belt conveyor - Coal

5.3 COAL – 51 KM LONG OVERLAND CONVEYOR

Another case study comparing Rail Conveyor technology to conventional trough conveyors looks to the growing need for ultra-long distance conveying. Here, the scenario was for a conveyor traversing a 51 km route over relatively flat terrain, with a total lift of 160 m. For a system of this length, an intermediate tripper drive appears to provide the most attractive configuration if the cost of installing a power line to the intermediate drive station is around $80,000 per km or less. Therefore, both the conventional and Rail Conveyor cases assumed an intermediate tripper drive, but in each case the location of the intermediate drive was selected to balance belt tensions in the two segments. Table 6 shows the specifications for the 51 km long coal conveyor for a 3000 mtph throughput.

Table 6. System specifications for 51 km long South African coal conveyor for 3000 mtph throughput.

	Units	Belt Conveyor / Rail Conveyor	
Design Capacity	mtph	3,000	
System	-	Belt	Rail
Warm Season Temp.	°C	30	30
Cool Season Temp. (For Belt Strength)	°C	8	8
Coldest Temp. (For Installed Power)	°C	0	0
Lift	m	160	160
Belt, ST Rating	-	3150	2250
Belt Width	mm	1200	1200
DIN f Equivalent - Warm Season	-	0.010	0.005
DIN f Equivalent - Cool Season	-	0.011	0.005
DIN f Equivalent - Coldest Operating Temp., High Drag	-	0.012	0.005
Total Installed Power	kW	13,500	6,000
Head Drives	-	4 x 1,500	2 x 1,500
Intermediate Drives	-	4 x 1,500	2 x 1,500
Tail Drives	-	1 x 1,500	0
Power at Design Tonnage, Warm Season	kW	10,333	5,560
Power at Design Tonnage, Cool Season	kW	11,068	5,560

The estimates comparing an owner's as-erected CAPEX as well as the projected OPEX are shown in Figures 21 and 22 respectively. Interestingly, Rail Conveyor CAPEX savings for a 3,000 mtph coal conveyor at 51 km length turn out to be similar to the 21 km example of the same duty discussed earlier, at about $28 M. This may be because the longest flight heavily influences the per-km cost, and an intermediate tripper drive makes the longest flight similar in length to the earlier 21 km example. That said, the per-km cost advantage of long Rail Conveyors should continue to accrue as the conveyor length increases.

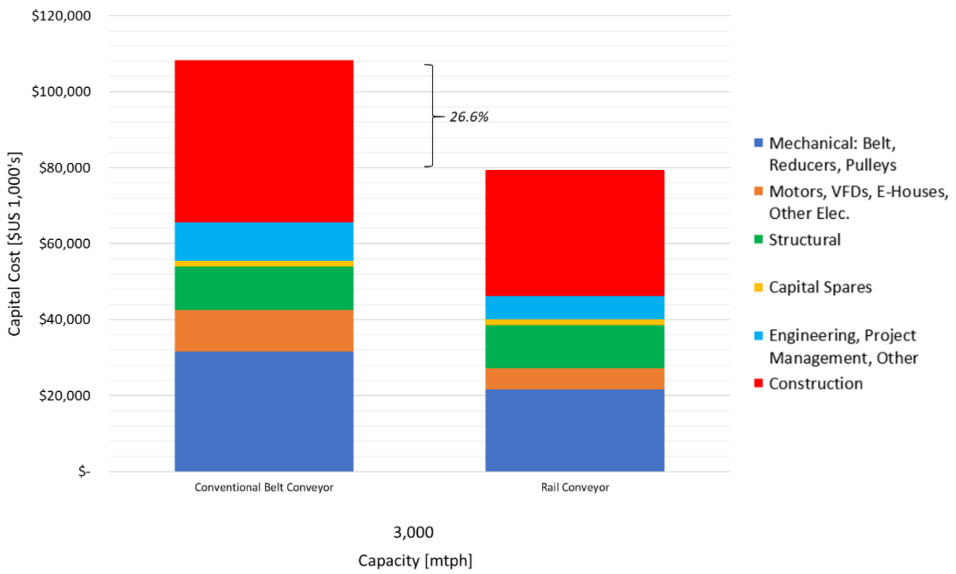


Figure 21. CAPEX vs capacity for Rail Conveyor system and conventional belt conveyor - Coal.

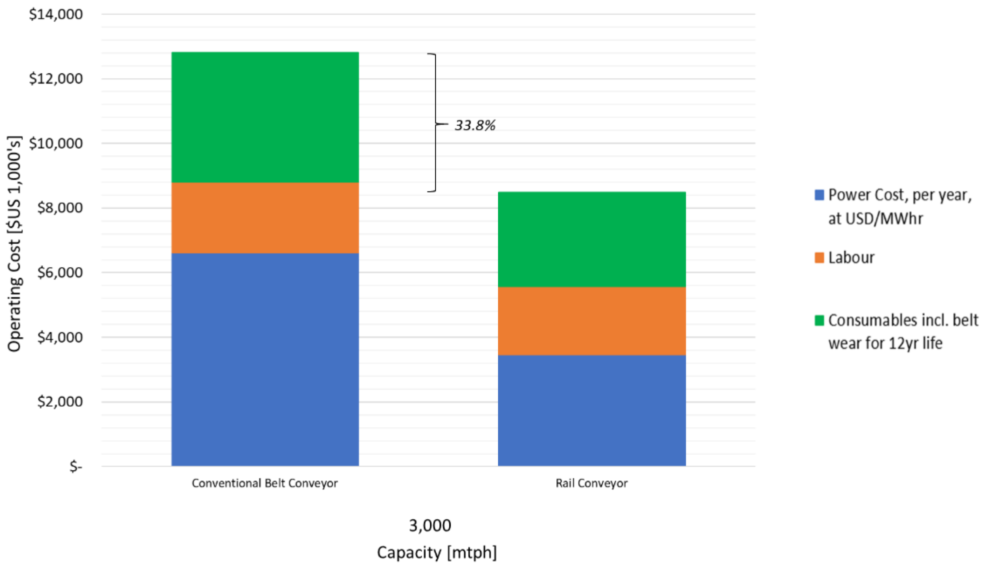


Figure 22. OPEX vs capacity for Rail Conveyor system and conventional belt conveyor - Coal.

6. CONCLUSIONS

This paper presented an overview of new light gauge rail-based bulk material handling systems. Both batch and continuous systems were presented, while track and rail considerations were discussed, with particular focus on the advantages of Independently Rotating Wheels (IRWs), guidance principles and the components of rolling friction. A number of case studies were presented comparing the CAPEX and OPEX comparisons for a continuous rail-running conveyor and a conventional belt conveyor.

The case studies presented considered long distance transportation of iron ore and coal in various countries where power, labour and operating temperature ranges varied considerably. The particulars of each conveyor system determine which characteristics have the greatest impact on CAPEX, but generally the characteristics that have the greatest influence stem from the lower rolling resistance and include; lower belt strength, reduced number of flights and transfer points, lower installed power at each drive station and resulting smaller electrical infrastructure. Additionally, narrower belt and supporting structures were also feasible due to the ability to trough the belt for optimal carrying capacity.

In relation to OPEX cost savings, these were primarily due to much lower power consumption, with negligible variation between cold and warm conditions, and idler failure costs and related safety issues largely eliminated. Furthermore, ease of inspection and replacement of the circulating track wheels will provide further benefits but were not considered in the economic comparison presented.

The pathway forward for rail-running conveyor systems, and in particular the Rail Conveyor system, is the implementation of a fully operational in plant system operating under industrial conditions. Fortunately, the belt, tail end configuration (i.e. loading point, tail pulley, etc), and the head end (i.e. discharge point, drive pulleys and take-up system) can be designed to be identical to a conventional belt conveyor, therefore significantly reducing the risks typically associated with introducing any new technology.

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