

Material Handling Evaluation for Company Operations for Coal Mining

ACEA 7009 – LEAN & AGILE MANUFACTURING SYSTEMS

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Abstract

This investigation delves into the evaluation of material handling systems for the transportation of coal from a mining site to a steel plant. The study focuses on three primary methods: an underground conveyor system, an underground slurry pipeline, and an aerial ropeway system. The slurry pipeline, although economically and environmentally promising, faces challenges due to additional processing steps and potential blockages, making it an impractical choice. The aerial conveyor system offers an economical solution but is hindered by its visual impact and vulnerability to adverse weather conditions. Ultimately, the underground conveyor system emerges as a strong contender, offering efficiency and minimal maintenance. Despite its higher cost, the system's underground nature mitigates visual and noise concerns. The study emphasises the importance of stakeholder involvement, regulatory compliance, and integration with Industry 4.0 technologies to enhance safety, reduce costs, minimise waste, and optimise overall efficiency in large-scale material handling operations. It underscores the need for a comprehensive approach when selecting a material handling system, considering various factors to ensure its viability and sustainability.

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Introduction

Coal mining is one of the most fundamental industries which is heavily reliant on efficient material handling methods. Coal, an abundant and versatile energy resource, plays a vital role in powering industries, generating electricity, and fuelling various processes worldwide. The extraction and transportation of coal demands for robust material handling systems that not only optimise operations but also address the environmental concerns associated with this fossil fuel (Meng, et al., 2013).

The history of coal mining spans millennia, beginning with its early use in ancient China and gaining prominence during the Industrial Revolution. This led to advancements in mining technology, the rise of mining communities, and labour movements advocating for workers' rights. The 20th century saw mechanisation and the development of mining towns. However, environmental concerns and the transition to cleaner energy sources have led to a decline in coal mining in recent years. Today, coal mining faces a future marked by sustainability challenges and the pursuit of cleaner alternatives (Hendrychová & Kabrna, 2016).

Material handling plays a pivotal role in industrial processes, influencing safety, efficiency, environmental impact, and overall operational performance. This paper delves into the meticulous evaluation and analysis of three prominent material handling systems: conveyor systems, slurry pipelines, and aerial ropeway systems. By scrutinising these methods across various criteria, including safety measures, cost, efficiency, environmental impact, and innovation, this research aims to provide a comprehensive understanding of its comparative strengths and weaknesses (Odell, 2023).

As industries worldwide strive for sustainability, this paper also underscores the importance of adopting environmentally friendly practices and harnessing technology and innovation. By synthesising these elements, businesses can not only enhance their operational efficiency but also contribute to a greener and more sustainable future.

Opening a coal mine may provoke public resistance, primarily due to the prevailing global imperative of achieving carbon neutrality through a reduction in fossil fuel consumption. Notwithstanding this imperative, the alternative energy sources characterised by environmental sustainability and reduced carbon emissions are yet to attain a level of development where they can entirely replace fossil fuels. Consequently, there remains a pragmatic necessity to establish new coal mines. The prospective establishment of a coal mine within the United Kingdom carries the potential to yield positive repercussions on the country's Gross Domestic Product (GDP), thereby engendering secure employment opportunities, fostering heightened economic activity, and positively contributing to the UK's trade balance.

1. Materials Handling Consideration

When embarking on the implementation of a material handling system, it is imperative to conscientiously evaluate various dimensions within the project scope. These dimensions can be categorised into four essential domains: safety, environmental impact, efficiency, cost, and sustainability (Castillo & Peters, 2010). A comprehensive consideration of these facets ensures the establishment of a safe, dependable, and environmentally sustainable operational framework.

1.1. Safety

Safety takes precedence in the material handling system. It should be prioritised above all else. Robust safety systems and fail-safe devices should be seamlessly integrated. A comprehensive training program and routine audits are essential for reinforcing safety (Rossi, et al., 2013). The Miners Regulation 2014 are in place to ensure safety during operation and must be conformed too.

An intricately designed emergency response plan is of utmost importance, necessitating communication to all employees. Regular testing and drills are essential to gauge its effectiveness. Equipment must meet required accreditations and undergo comprehensive testing before deployment. A manual document pack, complying with Provision and Use of Work Equipment (PUWER) 1998 regulations, promotes operational transparency and safety (HSE, 1998). Additionally, the machinery will need to conform to UKCA regulations to be able to operate safely in the United Kingdom and be able to be insured within the companies insurance and liability. The incorporation of pertinent sensors is indispensable for machinery to function safely within operational limits and to avert potential environmental hazards.

1.2. Environmental Impact

When assessing the environmental impact, a proactive emissions reduction plan assumes critical importance. These emissions encompass a range of pollutants, such as dust, particulate matter, and greenhouse gases, with the overarching goal of aligning with industry and governmental standards to achieve carbon neutrality (Kholod, et al., 2020). Diligence in addressing emissions facilitates regulatory compliance, thereby averting potential fines or probationary measures.

Furthermore, the strategic utilisation of natural resources like tidal, wind, and solar energy to meet operational requirements serves as an effective means to diminish the environmental footprint. Additionally, prioritising waste reduction through recycling, as opposed to resorting to landfill disposal, is imperative for environmental stewardship (Betz, et al., 2015).

1.3. Efficiency and Cost

In the quest for an optimised system design aimed at maximising material throughput while concurrently minimising energy consumption, operational costs, and waste generation. Each approach necessitates a thorough justification rooted in return on investment (ROI) analysis. The establishment of an acceptable payback period, ideally not exceeding 10 years for a project of this magnitude, assumes paramount importance in the assessment of feasibility. The concept of total cost of ownership (TCO) encompasses capital investments, maintenance, and operational efficiency considerations (Mo & Caporaso, 2021).

Furthermore, it is imperative to conduct a comprehensive evaluation of energy management systems to identify tailored technologies that place a premium on environmental outcomes through the implementation of energy-efficient practices. Proactive maintenance schedules are instrumental in prolonging the operational lifespan of equipment and preventing unforeseen downtime, ensuring the system's sustained efficiency.

1.4. Sustainability

To promote sustainability, implementation of efficient resource management strategies will leverage the skills of the workforce. Encourage work-life balance and enhance both productivity and morale by offering incentives such as flexible working arrangements, exemplified by the 9-day fortnight schedule.

Exploration of renewable materials and energy sources is essential for minimising the carbon footprint and reducing overhead costs. It is crucial to prioritise the use of recyclable or durable materials in the handling system.

Furthermore, the integration of technology plays a pivotal role in measuring and mitigating the carbon footprint through the implementation of energy-efficient practices.

2. Assumptions

For this project, there are several assumptions that need to be made in order to have a realistic outlook on each material handling system. The company possesses ownership of the land earmarked for excavation activities, which will serve as the primary site for mining operations. A continuous mining machine has been designated for the task, as shown in figure 1, efficiently extracting coal from subterranean depths and subsequently facilitating its transfer to the designated material handling system, which will be transferred over two miles. The extracted raw coal would be coking coal used in steelmaking. The mining operation is projected to yield substantial production volumes, with an estimated daily extraction and transportation capacity of approximately 11,000 tons of coal. The material handling system has been strategically designed to adhere to a linear trajectory, ensuring streamlined and efficient coal transport along a direct and unobstructed path. The annual revenue is expected to be £265m with an estimated 7% resulting in a profit of £18.5m annually.



Figure 1 - Example of a Continuous Mining Machine

3. Three Materials Handling Options

3.1. Option One- Underground Conveyor

The first potential method for coal transportation involves the utilisation of an underground conveyor belt system, representing a continuous loop mechanism designed to transfer coal from the extraction point to the steel plant. These systems have been used in several countries for various operations including; Grasberg Mine, Indonesia; Salt Mines in Hutchinson, Kansas, USA; and in the construction of the London Underground, United Kingdom. As shown in figure 2, there are several fundamental components in the system. Efficient drive units and idlers plays a crucial role in ensuring the smooth operation of the conveyor, maximising energy efficiency, and mitigating the risk of breakdowns (Murphy, 2023). To mitigate the visual impact of the conveyor system, an underground configuration is proposed.

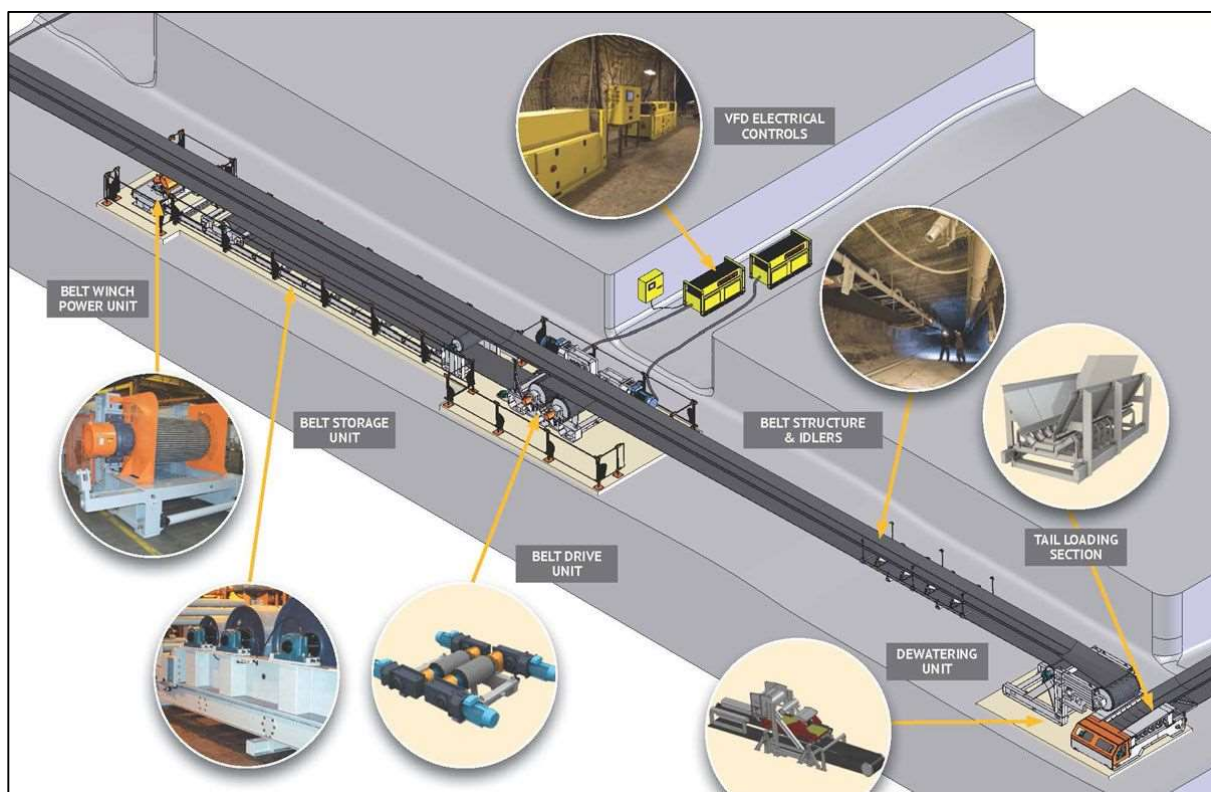


Figure 2 - Schematic of Underground Conveyor System, courtesy of (Syntron, 2020)



Figure 3 - Example of an Underground Conveyor in Kiruna, Sweden, courtesy of (Magazine, 2017)

Figure 3 shows an example of how the conveyor transports the materials. This example shows how many rollers are required in this section, with them being equally spaced. The figure also shows how wide the excavation needs to be to allow the conveyor belt system to operate along with an access route alongside the system. What is not shown in this example is any evacuation points, no emergency stops, no emergency lighting, and no guarding. This leaves the system exposed and an accident waiting to happen. There are solutions to overcome the machine guarding which are shown in figures 4, 5 and 6. This simple meshed guarded systems can dramatically reduce the risk of hazards and also complies with machine guarding regulations.



Figure 4 – Belt Conveyor with Full-length Belt and Idler Guards, courtesy of, (Janzé, 2016)



Figure 5 - Machine Guarding Example on a Conveyor, Courtesy of (Dirgie & Duffy, 2019)



Figure 6 - Alternate Machine Guarding Example on a Conveyor, Courtesy of (Rowland, 2014)

3.1.1. Advantages of Conveyor Systems

Conveyor systems have a longstanding presence in industrial applications, spanning several decades, and have earned recognition for their notable efficiency. The systems advantages include, efficiency, noise, visual, automation, cost savings as shown in table 1 below.

Number	Pro	Description
1	Efficiency	Modern underground conveyor systems are designed with energy efficient components and technologies, such as variable speed drives (VFDs) and energy-efficient motors. (Hou, et al., 2023).
2	Noise	Minimal noise is generated by the transportation process, rendering it inconspicuous to the general public, who may have limited or no awareness of its presence in the vicinity (Hou, et al., 2023).
3	Visual	This concealment extends to the visual aspect, as the conveyor system remains hidden from view (Hou, et al., 2023).
4	Automation	Leveraging available automation technology, the labour requirements for this system are significantly reduced, necessitating only a small team of operators (Skoczylas, et al., 2023). The chain of command below SMT level could include supervisor - team leader - operators.
5	Cost Savings	This reduction in labour contributes to cost savings by eliminating the need for manual material handling and concurrently enhances worker safety, which is carried out by co-bots etc (Skoczylas, et al., 2023).
6	Renewable Energy	The adoption of renewable energy sources within this conveyor system facilitates a reduced carbon footprint. This environmental advantage becomes particularly evident when comparing this system to conventional transportation methods such as rail, road, or sea (Skoczylas, et al., 2023).

Table 1 Underground Conveyor Advantages

3.1.2. Disadvantages of Conveyor Systems

Despite the well-established and accepted status of conveyor systems within the industry, it is imperative to acknowledge certain limitations associated with this method. There are several disadvantages to consider for a conveyor system which are explained in detail, in table 2 below.

Number	Con	Description
1	Protection	Due to the presence of numerous components in the conveyor system, and with the amount of dust emitted from the process, it is likely that the utilisation of higher specification bearings and protective coatings, such as nylon or hard surfacing alloys, will be necessary to ensure longevity. This adds operational costs and complicates conveyor maintenance (OCS, 2019).
2	Flexibility	Conveyors may exhibit limited flexibility when tasked with transporting larger coal pieces that fall outside the specified range, leading to potential blockages, equipment damage, material wastage, and operational delays (OCS, 2019).
3	Excavation	The material throughput necessitates a conveyor with considerable width, consequently requiring extensive excavation, which increases the capital investment when compared against other methods. The necessity for extensive excavation during conveyor installation inevitably leads to landscape disruption. This disruption can result in ecological damage, with the affected area requiring several years for natural regeneration to occur.
4	Electrical Consumption	Given the substantial number of motors and their large size, the associated electrical consumption can result in significant expenses. However, if renewable energy sources are integrated into the system, this expenditure can potentially be offset.
5	Confined Spaces	This approach introduces challenges related to confined spaces, necessitating engineered solutions to ensure operational safety. Furthermore, operating within an underground environment elevates the risk of asphyxiation, necessitating the implementation of appropriate safety controls, including the establishment of regular evacuation routes within the tunnel.

Table 2 - Disadvantages of an Underground Conveyor

3.1.3. Costs Associated with Underground Conveyors

There are currently plans in West Cumbria to open a coal mine and to use an underground conveyor as the plants material handling system. However, distance covered is said to be around four miles from the extraction point to the holding facility (Crack, 2022). Thus, the costs for the two-mile distance have been inspired by this facility and is represented in table 3 below. From this table, it can be budgeted to have a capital investment of ~£120million to install an underground conveyor at this site. Based on this, the ROI would be 6.5 years.

Conveyor CapEx	Cost at West Cumbria Mine	Predicted Cost for this Mine
Site Works	£ 58,500,000	£ 29,250,000
Mining Equipment	£ 63,800,000	£ 31,900,000
Mine Construction	£ 30,600,000	£ 15,300,000
Coal Prep Plant & Pressures	£ 23,900,000	£ 11,950,000
Coal & Refuse Handling	£ 24,400,000	£ 12,200,000
Other Costs	£ 15,800,000	£ 7,900,000
Contingency @ 10%	£ 21,700,000	£ 10,850,000
Total	£ 238,700,000	£ 119,350,000

Table 3 - Budget Costs for Underground Conveyor

3.2. Option Two- Slurry Pipeline

Slurry pipelines have a long-standing history of transporting materials over extensive distances, spanning several decades. This system has been utilised in several mines including transporting iron ore in Brazil, mineral sand in Australia, and Bauxite in Guinea. This transportation process comprises three fundamental stages. Initially, coal is subjected to a grinding process and combined with water to create a slurry. The coal preparation commences with impact crushing, followed by iterative water addition until the coal particles reach a size of one-eighth of an inch. Additional water is introduced to create a slurry composition consisting of approximately 50 percent coal by weight (Wang, et al., 2022). Subsequently, this slurry substance is conveyed through a pipeline to its intended destination. Figure 7 shows an example model of an underground pipeline with its support structure.



Figure 7 - Example of Underground Slurry Pipeline in Minas-Rio, Brazil, Courtesy of (McKay, 2018)

The transportation of the slurry entails its introduction into a subterranean steel pipeline, where it is pumped through the system. The slurry can attain velocities of up to 6 meters per second, allowing it to traverse the pipeline within a duration of 537 seconds (equivalent to 0.15 hours) until it reaches the steel plant. It is crucial for the flow to remain continuous to prevent potential settling of the slurry, which may result in pipeline blockages and obstructions (Rieber, 1978).

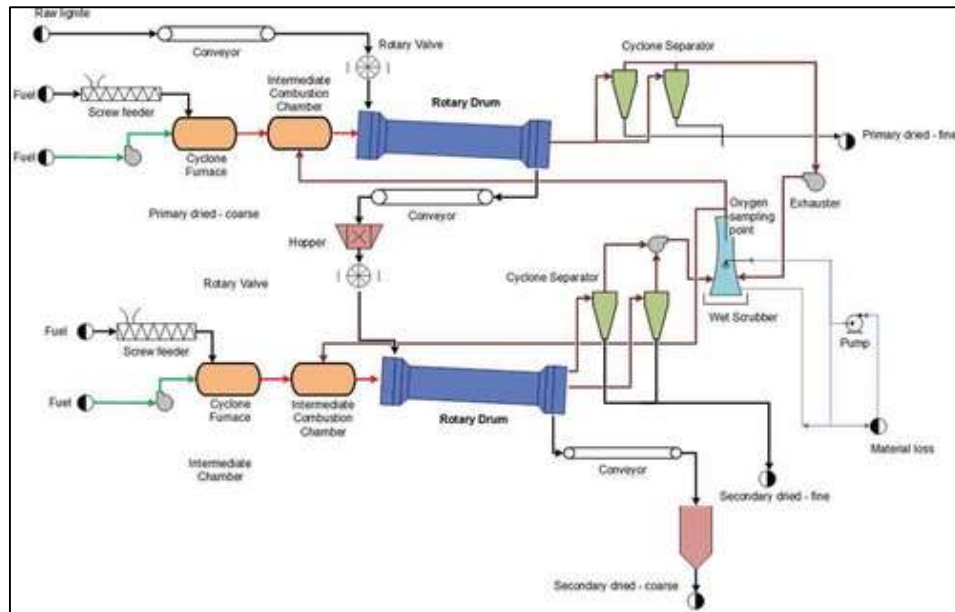


Figure 8 – Process Flow Diagram of a Drying Process for Coal, Courtesy of (Phiciato & Yaskuri, 2017)

Upon reaching its final destination, the slurry undergoes a dewatering process, typically involving a rotary drum. Figure 8 shows a P&ID of how this drying process could work and then figure 9 shows a 3D model of how the set up could be achieved. To remove dust from the dryer, a cyclone is used to separate particulate from the steam generated. The particulate would drop out of the bottom of the cyclone and the steam would be extracted through a wet scrubber and then any clean gasses be vented out of the stack.

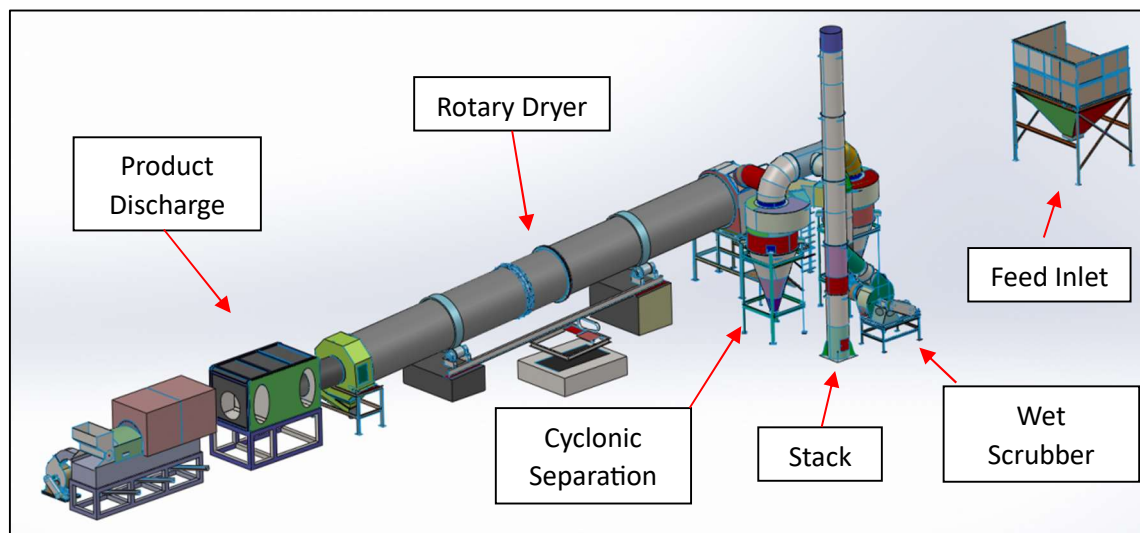


Figure 9 - 3D Layout for a Coal Drying Plant, Courtesy of (ARGE, 2022)

3.2.1. Advantages of a Slurry Pipeline

Slurry pipelines is a great option for transporting coal as its advantages include; environmentally friendly, limits segregation in the process, mitigates dust, is unaffected by weather conditions, can handle large volumes, can recycle waste from the process and does not emit pollution from the process. The full description of these advantages can be seen in table 4.

Number	Pro	Description
1	Environmental	The utilisation of such a pipeline system effectively minimises ground disturbance, as the excavation of the pipeline route can be carried out without disrupting natural landscapes and habitats (Bertram & Kaszynski, 1986).
2	Segregation	The grinding process employed in slurry preparation ensures a consistent size of coal particles (max. 300 micron) during transportation, thus reducing material segregation and enhancing the overall efficiency of this transportation method (Bertram & Kaszynski, 1986).
3	Dust Mitigation	The dewatering process implemented in the system significantly mitigates dust emissions throughout the transportation process, thereby positively contributing to improved air quality in the surrounding area.
4	Unaffected by weather	As the pipes are underground the process is unaffected by any weather condition.
5	Large Volumes	Pipe diameters can be designed to suit any transportation volumes.
6	Water Recyclability	The water used in the slurry mix can be recycled via a water filtration plant which can be used reused in future slurry mixtures and/or in power generators (Bertram & Kaszynski, 1986).
7	No Pollution	With the recycling of water, using renewable energy sources for pump operations, means there is no pollution omitted from this transportation process.

Table 4 - Pros of a Slurry Pipeline

3.2.2. Disadvantages of a Slurry Pipeline

While slurry pipelines offer numerous advantages, they also entail several drawbacks that warrant consideration. From table 5, several disadvantages can be seen which include; intricate engineering, landscape distribution, specialist maintenance, wear and tear, short distances, additional process steps, block, and poor flexibility. Also, in table 5 is an in-depth description of each issue with this process.

Number	Con	Description
1	Intricate Engineering	The development of an efficient slurry pipeline system involves intricate engineering endeavours, encompassing considerations related to physical design, pressure drop, transport routes, and velocity parameters. Consequently, this complexity can restrict the flexibility of pipeline routes and configurations (Wang, et al., 2022).
2	Landscape	Although the installation phase generally entails limited landscape disruption, routine maintenance activities may necessitate such disruption.
3	Maintenance	The maintenance process demands specialised machinery, leading to operational interruptions.
4	Wear & Tear	Over time, wear and tear within the system may manifest as erosion on the pipeline walls, potentially resulting in contamination issues and operational downtime.
5	Short Distance	Slurry pipelines demonstrate greater economic viability over longer distances, typically spanning tens of miles, and may pose economic challenges when applied to shorter transportation routes. This is primarily due to the requirement for custom-designed, specialised machinery, particularly for the loading and unloading processes, which introduces complexity and additional costs to the system (Wang, et al., 2022).
6	Drying Process	An additional process step is required to dry the coal from the slurry. This adds process time, operational costs such as energy, labour, and maintenance along with additional capital expenditure (CapEx) costs to purchase and install the drying facility.
7	Blocks	The walls of the pipe are prone to build up due to friction. This can lead to opening of the pipe reducing which reduces throughput and will eventually block where downtime and expensive maintenance will occur.
8	Poor Flexibility	Other methods required to achieve "door-to-door". Which adds cost to the complete material transportation methods (Wang, et al., 2022).

Table 5 - Cons of a Slurry Pipeline

3.2.3. Costs and Considerations for Slurry Pipelines

The cost for this system is outlined in table 6 below. The cost has been inspired where this similar system was used in 1976 for the transportation of materials for the US department of mines. However, as inflation has risen dramatically since then, costs have been estimated on a total inflation value of 4.73 times higher for 2023 (England, 2023), taking the capital investment for this pipe run to ~£3m. For the dryer cost, the investment and operation costs would expand into the millions of pounds. At an estimated £10m for the dryer system and infrastructure, this would take the investment cost to ~£13m. This results in a ROI in 0.7 years.

Slurry Pipeline CapEx	Cost in 1976	Cost in 1976	Cost in 2023
Pipeline 16" Dia @ \$92,072/mile	\$184,144	£102,302	£805,772
Land & Improvements	\$32,500	£18,056	£142,216
Structures & Building	\$35,000	£19,444	£153,149
Motor Compressor	\$325,000	£180,556	£1,422,131
Bins & Venturi	\$12,000	£6,667	£5,254
Eng & Config	\$68,720	£38,178	£300,705
Electrical @ \$0.24/ft	\$2,535	£1,408	£11,090
Total	\$659,899	£366,611	£2,840,316

Table 6 - Budget Costs for Slurry Pipelines

The Pressure Systems Safety Regulations (PSSR) in the United Kingdom govern the safe operation and maintenance of pressure systems that contain relevant fluids and operate at pressures exceeding 0.5 bar. Duty holders, including employers and system owners, are responsible for ensuring compliance with PSSR. A key requirement is the development and implementation of a Written Scheme of Examination (WSE) by a competent person, outlining examination and inspection schedules. Pressure systems must undergo periodic examinations, the frequency determined by risk and the WSE. Notification of certain circumstances to the Health and Safety Executive (HSE) is mandatory. Records of examinations and maintenance must be maintained, and personnel involved in pressure system operation must be competent and trained. Enforcement by the HSE ensures compliance, with penalties for breaches, ensuring the safety and integrity of pressure systems.

3.3. Option Three- Aerial Ropeway Systems

An aerial ropeway system, also recognised as an aerial tramway or cable car system, constitutes a mode of transportation that employs cables, gondolas, and pulleys to facilitate the movement of materials between multiple points. The system has been successfully used in Sugarloaf Mountain, Brazil, Cerro de Pasco, Peru and Bingham Canyon Mine, USA to transport materials. This system shares similarities with ski lifts or gondola rides but is specifically designed for cargo transport, as shown in figure 10.



Figure 10 - Example of Aerial Ropeway System in Santiago De Los Caballeros, Courtesy of (POMA, 2023)

The process commences with the loading of coal into carriers or gondolas at the mine's loading station. Subsequently, the aerial ropeway system is set into motion, with a continuous movement of the haulage cable until it is unloading at the steel plant.

The cables utilised in the aerial ropeway system are constructed from steel strands meticulously wound around the core of the ropes (Walker, 2012). Typically, the structural cable comprises up to eight complete wire strands wound around the core, with each strand composed of hundreds of smaller strands. Similarly, the support rope undergoes a similar manufacturing process and is subsequently tensioned between each station. The system hinges on two primary cables: a haulage cable responsible for conveying the carriers or gondolas and a support cable that offers structural stability (Petrova, et al., 2007). The schematic in figure 11 summarises this.

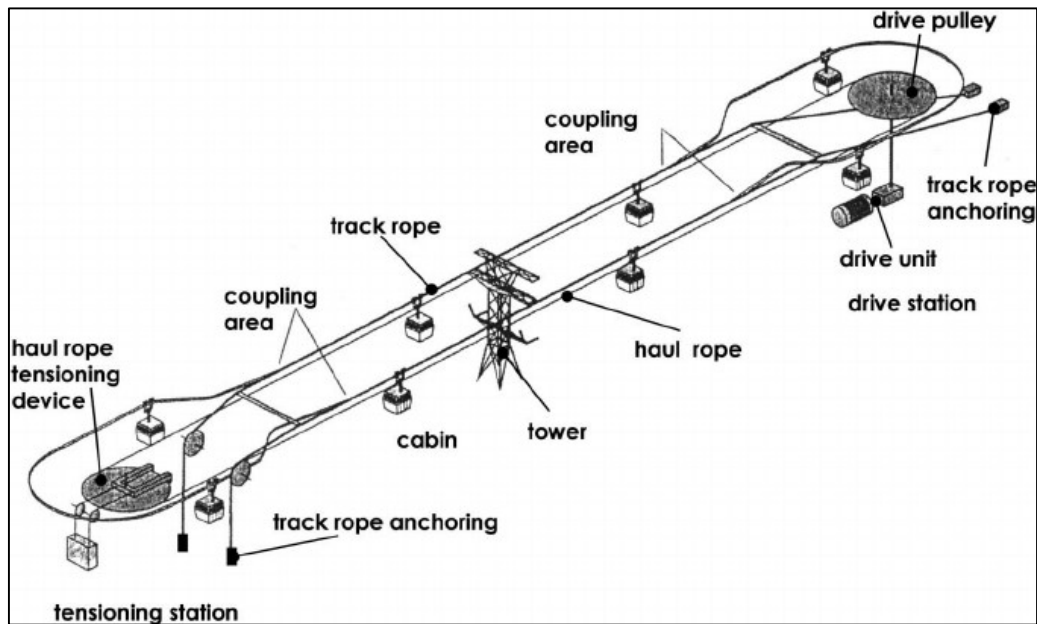


Figure 11 - Overview of Aerial Ropeway System, Courtesy of (Petrova, et al., 2007)

The carriers, designed to accommodate coal during transportation, hang suspended from the haulage cable and traverse along the designated route. Using a 0.125m^3 cart as an example (1m W x 0.5m H x 0.25m D) it accounts for 107kg being transported in each cart. To achieve the throughput demand, it is estimated that 280 carts would be needed and be running at 4m/s (POMA, 2023). Necessitating consideration during the design phase to facilitate structural calculations for cables and support towers. To meet transportation demands, a specified number of carriers, each weighing a certain amount and operating in multiples, are employed.

Towers serve the dual role of supporting and guiding the cables, while pulleys facilitate cable direction changes as required. These structures assume considerable height to prevent ground interference due to cable sagging resulting from the applied load. Interspersed between the loading and unloading stations are a predetermined number of support stands, strategically positioned to minimise cable sag, as shown in the schematic from figure 12.

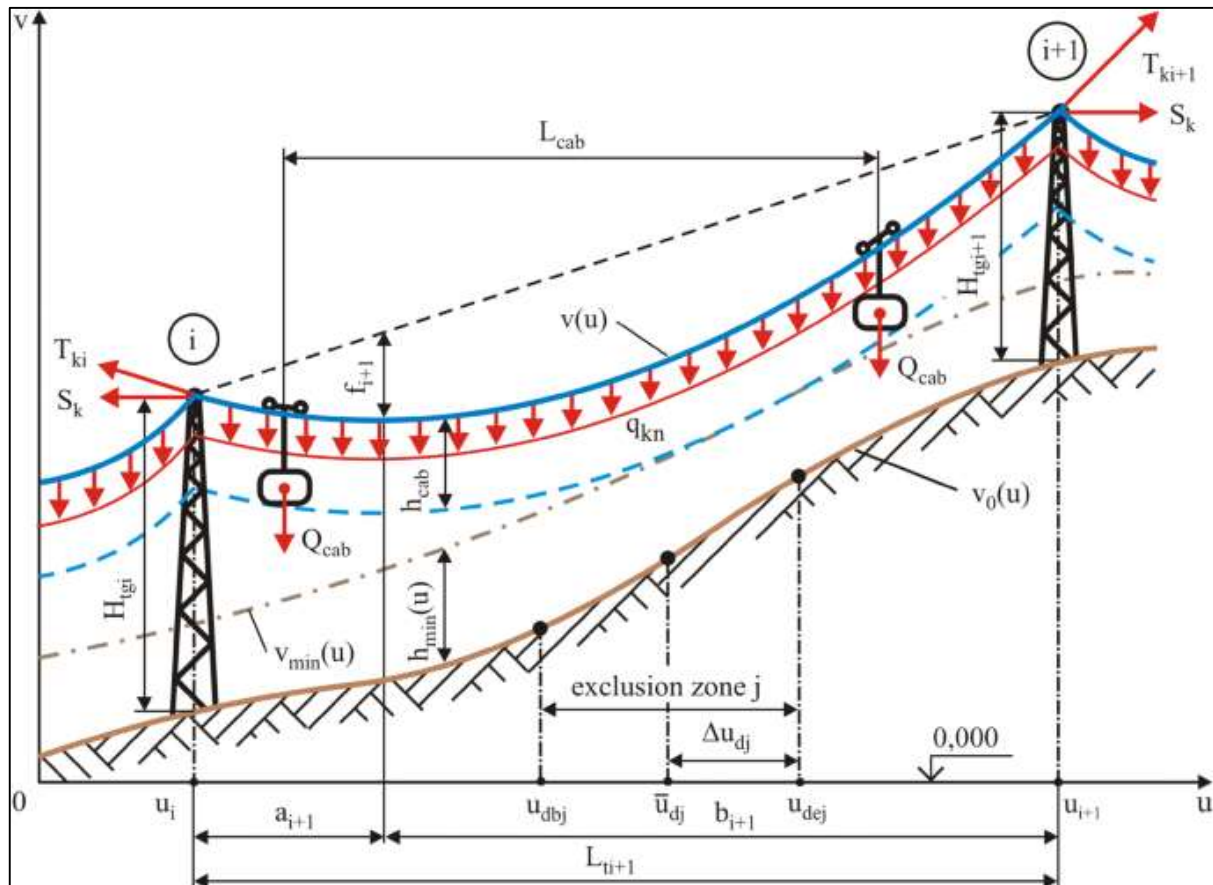


Figure 12 - Aerial Ropeway Design Considerations, Courtesy of (Lagerev & Lagerev, 2019)

The installation of these supports entails minor excavations for footing, with the ground condition dictating the potential need for pile installations to ensure secure anchoring. Sample assessments and analyses should be conducted and subsequently evaluated by a structural engineer to inform the design (Lagerev & Lagerev, 2019). At one end of the ropeway, a drive station assumes responsibility for powering cable and carrier movement, typically housing the motor and control systems. The control system necessitates inverter-based control to enable variable speed adjustments in response to applied loads.

Implementation of Industry 4.0 techniques facilitates the creation of a digital twin and the incorporation of various sensors and load cells. This data-driven approach automates speed control, thereby enhancing safety by mitigating human error factors.

3.3.1. Pros for Aerial Ropeway Systems

For an ariel ropeway system, there are several advantages that come with this system. The full range can be seen in table 7 below along with a description for each inspired by (Lagerev & Lagerev, 2019).

Number	Pro	Description
1	Noise	An advantage inherent to aerial ropeway systems lies in their relatively low noise levels during operation. Audible disturbances are primarily associated with the loading of carts, the traversal of the support rail over rollers, and the unloading process. Notably, noise generated during unloading is generally overshadowed by the ambient noise at the steel plant.
2	Visual	Despite the system's visual prominence, this characteristic can be leveraged to attract public interest and serve educational purposes, potentially boosting tourism and providing economic support to local businesses.
3	Environmental	The environmental friendliness of aerial ropeway systems is evident, as they do not rely on combustion engines, and the pumps utilised can be powered by solar energy. This not only reduces electricity expenses but also contributes to a reduced carbon footprint. Offsetting the use of fossil fuels by using renewable energy for transportation so it can be utilised in other industries, all while wildlife can still roam under the system.
4	Distance	These systems are particularly well-suited for short-distance transportation routes, typically spanning up to 8 miles, making the proposed two-mile route well-aligned with this operational scope.
5	Flexibility	The flexibility of aerial ropeway systems becomes evident in their ability to facilitate material transport across various terrains, including hilly and valley regions.
6	Labour	Verry little labour required to operate the system. This clearly demonstrates this transport method is very economic by comparison to other competitive systems.
7	Safety	One of the safest, smoothest, and most reliable modes of transport.

Table 7 - Advantages for Arieal Ropeway Systems

3.3.2. Cons for Aerial Ropeway Systems

Although an aerial ropeway system is very advantageous, there are disadvantages that come with this system. These are explained in table 8 below.

Number	Con	Description
1	Adverse Weather	One of the primary drawbacks associated with this material handling system pertains to its susceptibility to adverse weather conditions, which can significantly impact its operational reliability. Notably, the absence of shelter or wind deflectors renders the system vulnerable to medium to high winds, rendering it inoperable when wind speeds exceed a threshold of 15 meters per second (55kph) (Technology, 2008).
2	Capacity	The presence of an increased number of carts simultaneously traversing the line necessitates the deployment of additional support structures, thereby escalating project costs.
3	Falling Objects	The inherent risk of falling objects in the vicinity of the system discourages the establishment of general access routes under the length of the run. Consequently, it becomes imperative to restrict access to the area, permitting entry only to authorised personnel.
4	Specialist Maintenance	Maintenance ladders affixed to the towers offer accessibility for upkeep activities; however, it is essential to emphasise that such tasks can only be undertaken by skilled engineers. This reliance on skilled contractors for maintenance contributes to elevated outsourcing costs, given the specialised expertise required for the job (Lagerev & Lagerev, 2019).
5	Spares	In the event of damage to any of the ropes, the system faces substantial downtime due to the impracticality of maintaining a spare cable of this size. This issue necessitates visual representation for comprehensive understanding.
6	Open Buckets	In cold/wet weather, moisture can build on the coal causing problems in the steel plant. A drying process would need to be considered, which will incur additional capital and operational expenditure costs.

Table 8 - Disadvantages of Aerial Ropeway Systems

3.3.3. Cost for Aerial Ropeway Systems

Similarly, to the slurry pipelines, the costs of the transportation line have been based off a historic installation in 1981. Again, considering inflation of 4.73 times to price in 1981 (England, 2023) it can be estimated that a capital investment of £18.25 million would be needed to install this facility. This gives a ROI of 1 year.

Investment Costs		
Item	Cost 1981	Cost 2023
Machinery parts, steel structures and electrical equipment, free to construction site	£2,100,000	£9,926,772
Ropes free to construction site	£450,000	£2,127,165
Installation	£650,000	£3,072,572
Construction work	£550,000	£2,599,869
Other expenses	£110,000	£519,974
Total	£3,860,000	£18,246,352
Operating and transport costs		
Item	Cost 1981	Cost 2023
7% interest in invested capital	£270,000	£1,276,299
Amortisation of system in 20 years excluding ropes (2.44 %)	£85,000	£401,798
Amortisation of the ropes in 5 years (17/4%)	£75,000	£354,528
Personnel costs (two shifts/day)		
Item	Cost 1981	Cost 2023
1 foreman	£14,000	£66,178
1 specialist	£10,000	£47,270
7 trained workers	£85,000	£401,798
Maintenance. Lubricants, etc.	£35,000	£165,446
Operating and transport costs per year	£550,000	£2,599,869
Operating and transport costs per tonne	£0.42	£1.99

Table 9 - Costs for an Aerial Ropeway System

4. Evaluation of Material Handling Options

To evaluate each of the material handling systems, there are several criteria points to compare. For this comparison, it takes the pros and cons of each system and can be summarised into a table where a rating and a weight can be applied. The purpose of this system is to give an overall score to aid in deciding the best material handling system for this operation. For the evaluation, there will be four steps to obtain a consensus. Step one is to identify the criteria. Once the criteria is formed, a baseline assessment is required so others can be compared too. One of three proposed methods will be needed to chosen to be the baseline, which in this case will be the underground conveyor. Step three will evaluate the remaining two methods against the baseline to give an overall score. In the final step, a weighting will be assigned to each criterion to assign importance to the criteria to give a more representative score. For this analysis, a one to 5 scale is going to be used for both the weighting and each criterion, as shown in table 12. For the baseline rankings, one to two will be the worst performing criterion, four to five will be the highest achievement and three will be the medium value. For the weighting scale, a score of one is a lot worse than the baseline design, a score of two is worse than the baseline design, three is the same as the baseline design, four is better than the baseline design and five is a lot better than the baseline (Coile, et al., 2023).

Table 10 presents a comparative evaluation of three material handling systems: Conveyor, Slurry Pipeline, and Aerial Ropeway Systems, across various criteria, each assigned a specific weight. The criteria considered in this evaluation encompass safety measures, visual and noise impact, cost (capital), operating costs, efficiency, environmental impact, capacity and scalability, flexibility, ROI (Return on Investment), permitting and compliance, reliability and maintenance, technology and innovation, and project timeline.

Criteria	Weight	Conveyor	Slurry Pipeline	Aerial Ropeway Systems
Safety Measures		5	4	4
Visual & Noise Impact		4	4	1
Cost (Capital)		2	4	3
Operating Costs		3	4	3
Efficiency		4	4	4
Environmental Impact		3	3	4
Capacity & Scalability		5	4	3
Flexibility		3	3	4
ROI		2	4	5
Permitting & Compliance		3	3	3
Reliability & Maintenance		4	3	3
Technology & Innovation		4	2	3
Project Timeline		3	2	3
Total		45	44	43

Table 10 - Criteria Matrix

Table 12 presents the same evaluation but with weighted scores, providing an overall score for each material handling system. Based on the weighted evaluation, Conveyor and Aerial Ropeway Systems achieved the highest and lowest overall scores, respectively, while Slurry Pipeline falls in between.

Analysing the results, the underground conveyor stands out with the highest total score of 169, indicating a slightly better overall performance when considering the specified criteria and its respective weights. Aerial ropeway systems scores the lowest with a total of 161, and the slurry pipeline falls in the middle with a total score of 166.

Criteria	Weight	Conveyor	Slurry Pipeline	Aerial Ropeway Systems
Safety Measures	5	25	20	20
Visual & Noise Impact	3	12	12	3
Cost (Capital)	4	8	16	12
Operating Costs	4	12	16	12
Efficiency	4	16	16	16
Environmental Impact	5	15	15	20
Capacity & Scalability	4	20	16	12
Flexibility	3	6	9	12
ROI	3	6	12	15
Permitting & Compliance	4	12	12	12
Reliability & Maintenance	4	16	12	12
Technology & Innovation	3	12	6	9
Project Timeline	2	6	4	6
Total		169	166	161

Table 11 - Weighted Criteria Matrix

Low	1-2
Medium	3
High	4-5

Table 12 - Criteria Ranking System

5. Issues to be Considered as Part of Procurement

A timeline should be presented to show when costs and revenue are being exerted to manage stakeholder expectation and the tangible and intangible costs. Calculating the net present values by subtracting costs from benefits to give an efficient investment, yields a positive result.

Specific reports may be generated based on the significance of the impact or the need for specialised expertise. These reports may cover areas such as cumulative impact assessment, climate change impact assessment, biodiversity offset management plan, reservoir management plan, gender, and ethnicity development plan, among others. It is imperative to share and discuss these reports with relevant local and national stakeholders. By involving stakeholders, it will allow for decisions to be made more effectively and to avoid delays during the project (Liu, 2022).

5.1. Health, Safety and Environmental

Safety can be influenced by procurement teams in several ways. It is important to ensure safety policies are up to date and implemented before any production begins. All works being conducted on site needs to be authorised using an authorisation to work permit system which will include risk assessment and method statements (RAMS) from the contractors. This ensures all parties are aware of what activities are taking place, when and what risks are associated with each task.

This project would be within the CDM regulations and will require notification to the HSE which on times, may audit onsite works or project files. It is key that all activities are logged and saved in an accessible folder along with the projects plan which should be updated on a regular basis. It is important to be compliant throughout the project to avoid fines, lawsuits, and shutdown (Mori-Clement, 2019). Non-compliance can be seen when not operating within permit limits, breaching any non-disclosure agreements or to the general data protection regulations (GDPR).

An Environmental Impact Assessment (EIA) is a pivotal tool for assessing the significant environmental and social impacts of a project. The EIA process involves multiple steps, often contingent on prevailing laws and regulations within specific administrative areas. A comprehensive evaluation phase follows, with a report containing project details, impact assessments, proposed solutions, monitoring strategies, and budget allocations for implementation (Gargalo, et al., 2024).

5.2. Logistics

Since the COVID 19 pandemic there has been an increase in lead times for materials along with a significant price increase. There are considerable lead times on microchip components which are used in programmable logic controllers (PLC) and automation devices, which can lead to delays for installations.

Obtaining quotes from a minimum of three suppliers promotes fair market competition and budget adherence. However, prioritise contractor experience and expertise alongside cost considerations, as the cheapest option may not always be the best choice. This will also avoid dark purchasing. Developing a technical specification detailing key supplier requirements to streamline the quotation process and ensure alignment among all parties (Liu, 2022).

Supplier management represents one of the most significant challenges in procurement. It involves a complex process, ranging from the initial supplier selection to monitoring vendor performance and maintaining a consistent supply of high-quality products.

Recommendations

Throughout this investigation, the focus has been to compare which material handling system would be best suited to transport coal from the coal mine to the steel plant between an underground conveyor, underground slurry pipeline and an aerial ropeway system.

Slurry pipelines themselves are a very good economic and environmentally friendly transport method. However, due to additional process steps in the form of grinding and drying processes makes the process unfeasible. Additionally, the risk of blockages are a cause for concern along with the expertise needed for complying with the pressure systems safety regulations (PSSR), meaning this system wouldn't be suitable.

The second method was the aerial conveyor which would been a strong contender if it wasn't for two critical drawbacks. The simplistic and recognised design would be very economical for this project. The first drawback being the system is a big eye soar and the second is the nonoperation in adverse weather conditions.

This leaves the underground conveyor which ticks all the boxes bar one, cost. The cost for this system is the highest by some margin compared to the other two methods. However, the use of the system being underground eliminates the visual and noise risks. This system is highly efficient and near maintenance free.

There are several considerations that need to be made when implementing a material handling system of this size. Firstly, it is critical to involve all necessary stakeholders to have their input and all parties to be on the same wavelength. There are a lot of regulations and legislations that need to be complied with such as The Miners Regulations 2014. The adoption and integration into Industry 4.0 will have significant benefits to reduce and improve safety, reduce handling costs, reduce waste, and to have a more efficient process by utilising sensors and data capture.

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