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Coal Transport Optimization: A Geodesic based Productivity Enhancement Model

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ABSTRACT
Growing coal demand and rising production pressures in opencast mining have long prioritised output over energy efficiency. With escalating energy costs and tighter GHG regulations, the industry now requires smarter, sustainability-driven transport solutions. This study proposes a pioneering dual-framework that blends an Operations approach with a sustainability assessment to rethink mine transportation. The Geodesic Transport Optimization Model (GTOM) introduces geodesic path analysis to derive the most efficient transport route between extraction and deposition points, enabling a robust comparison of haul trucks and conveyor belts for cost-effective productivity improvement in Indian opencast mines. Alongside, the Sustainability Assessment Model (SAM) evaluates the environmental performance of both systems, offering a comprehensive measure of long-term ecological viability. Together, GTOM and SAM present a transformative pathway for the mining sector supporting decision-makers in achieving higher productivity while ensuring regulatory compliance, reduced emissions, and resilient, future-ready operations

Keywords: Geodesic Transport Optimization, Coal Transportation, Sustainability Assessment Model, Productivity

INTRODUCTION:

Opencast (OC) coal mines face a persistent transportation challenge, as large volumes of overburden and coal must be moved efficiently from the extraction face to processing or dispatch locations. This movement forms the backbone of mine productivity, yet remains one of the costliest and most operationally demanding components of the mining cycle. Traditionally, coal transportation has relied heavily on haul trucks, which travel continuously between the pit and the dumping or processing points. These trucks operate in a repetitive up-and-down cycle along mine benches, navigating steep gradients, long travel distances, and varying geological conditions. The huge cost involved per truck is around Rs. **5,85,983/day** (Clark et. al., 2019). The parameters involved in calculating this cost is shown Table -1 below:

Parameters	Value
Total distance/day/truck	26 KM
Truck capacity	40 Tonnes
Time per round trip	1.08 hrs
Total time spent hauling	5.5 hrs

Table-1: Haul Truck

While haul trucks remain the most widely used method due to their flexibility, they also introduce significant sustainability concerns. High diesel consumption contributes to increased greenhouse gas emissions, and frequent mechanical strain leads to elevated maintenance requirements. Moreover, the continuous movement of heavy trucks poses notable safety risks, including collisions, slope-related accidents, and operator fatigue. Together, these issues highlight the need for more efficient, safer, and environmentally responsible transportation approaches in opencast coal mining. To address these transportation challenges, this research study explores the need for a more efficient, safer, and environmentally responsible alternative to the conventional haul truck system. It introduces an analytical approach that evaluates optimized transport routes and compares them with other potential systems, such as conveyor belts, to reduce fuel consumption, minimize emissions, and lower accident risks. By applying advanced modelling techniques, the research study tries to identify solutions that can significantly enhance productivity while supporting long-term sustainability in opencast coal mines.

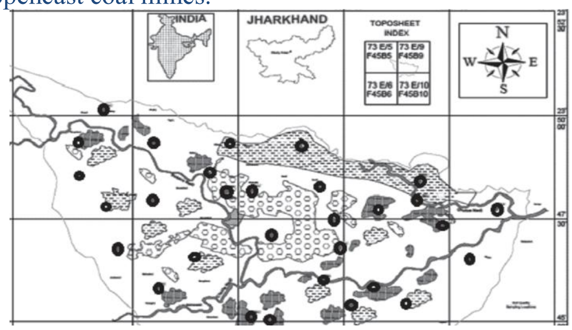

Fig 1: The study area of coal mine in Jharkhand

2. Rationale

Coal mine haulage dominates both operating cost and the environmental footprint of surface mining, so methodical optimization of transport systems is central to decarbonizing the sector while preserving productivity (Yao et al., 2023; Al-Habib, Ben-Awuah & Askari-Nasab, 2023). In practice, truck–shovel fleets remain ubiquitous because of their flexibility, yet energy use, diesel combustion emissions, and dust from haul roads make them the highest-impact element of open-pit operations (IPCC, 2019; U.S. EPA, 2011; Nassar et al., 2025). Conveyor-based systems—including variants of in-pit crushing and conveying (IPCC)—offer markedly lower specific energy and can be engineered for regenerative power on downhill gradients, but alignment and terrain constraints are decisive for feasibility and performance (Kawalec & Suchorzynska, 2020; Dindarloo, Osanloo & Frimpong, 2019; de Souza et al., 2023). Recent techno-economic and sustainability assessments increasingly compare truck haulage with conveyor/IPCC options using life-cycle or operational energy and GHG metrics, generally finding substantial reductions in energy intensity and emissions when trucks are displaced by conveyors for mainline haulage (Nassar et al., 2025; de Souza et al., 2023; Dindarloo et al., 2019). These themes motivate transport models that treat topography not as a rough heuristic but as a first-class optimization variable. Operations Research (OR) for mine haulage has matured from fixed truck allocation toward dynamic dispatching, simulation–optimization, and, recently, reinforcement learning, yet most formulations embed distance using planar metrics or piecewise linear approximations that under-represent the curvature and slope structure of real terrain (Munirathinam & Yingling, 1994; Subtil, de Souza & Neto, 2011/2020; Yao et al., 2023; Zhang et al., 2024). That simplification is consequential because on undulating pit geometries, the “shortest” path in plan view can be inferior in grade-resistance, fuel burn, and conveyor power relative to a surface-aware path (U.S. EPA, 2011; IPCC, 2019). Integrating surface geometry directly into the optimization thus offers both physical realism and better sustainability outcomes. Geodesic modelling provides that surface-aware foundation. In computational geometry and GIS, a geodesic is the length-minimizing curve constrained to a surface; on triangulated terrains (polyhedral surfaces), exact or provably approximate algorithms compute such paths with formal guarantees (Mitchell, Mount & Papadimitriou, 1987; Lanthier, Maheshwari & Sack, 2000; Cheng et al., 2007; Agarwal et al., 2014). Beyond pure distance, engineering studies extend geodesics with anisotropy, slope or curvature penalties, and turn-cost terms—attributes directly relevant to haulage and belt routing (Arnold et al., 2011; Han et al., 2021; Hao et al., 2012; Hildebrand et al., 2013). In ecological GIS and landscape connectivity, the distinction between truly surface-constrained geodesics and raster “least-cost paths” (LCP) is well-documented; LCPs on coarse DEMs can bias path length, slope accumulation, and energy surrogates, underscoring the importance of resolution and surface-true path computation (Etherington, 2016; Etherington, Holland & O’Sullivan, 2020). Digital Elevation Models (DEMs) underpin such approaches; 30 m global products like NASA’s SRTM and the Copernicus GLO-30 DEM offer sufficient resolution for network-scale geodesic routing while remaining computationally tractable (NASA LP DAAC/JPL, 2013; USGS, 2018; Copernicus Programme, 2021). Nonetheless, DEM choice and resolution materially affect derived slope/curvature and hence the optimal path; sensitivity and multi-resolution workflows are widely recommended (Etherington, 2016; Etherington et al., 2020). Within mining, IPCC planning and shovel–crusher–conveyor integration are an active research frontier, with short- and medium-term models that co-optimize crusher relocations, shovel allocation, and haulage under topographic constraints (Al-Habib et al., 2023; Dindarloo et al., 2019; de Souza et al., 2023). These methods consistently report lower unit costs and emissions when conveyors substitute long uphill truck hauls—particularly as pits deepen—yet route geometry, maximum grades, and curve radii remain hard constraints for belts (Kawalec & Suchorzynska, 2020; Nassar et al., 2025). A terrain-constrained geodesic layer directly addresses this by generating grade-feasible alignments that minimize surface distance (or generalized “action” with slope/curvature penalties), forming an OR-ready network for flow, capacity, and scheduling decisions. Truck-focused OR literature complements this picture. Decades of dispatching work—ranging from linear/integer programming through agent-based systems, simulation–optimization, and deep reinforcement learning—target queueing, shovel balance, and travel-time variability (Subtil et al., 2011/2020; Bastos, 2013; Torkamani & Askari-Nasab, 2013; Yao et al., 2023; Xu et al., 2024). In all cases, incorporating path geometry improves predictions of travel time and fuel burn because grade resistance is a nonlinear driver of both (U.S. EPA, 2011; IPCC, 2019). A geodesic transport layer therefore augments dispatchers and simulators with physically consistent path lengths and slopes, narrowing the gap between plan and realized performance.

Environmental externalities further strengthen the case. Fugitive dust emissions scale strongly with vehicle weight, speed, and silt loading on unpaved haul roads (U.S. EPA, 2011), while diesel CO_2-e emissions are well characterized by mobile combustion factors (IPCC, 2019). By shifting mass flow from trucks to conveyors along geodesically optimized alignments—especially on downhill legs where regenerative braking is feasible operators can reduce both direct fuel use and secondary dust formation (Kawalec & Suchorzynska, 2020; Nassar et al., 2025). Collectively, these strands suggest a clear research gap: most mine-haulage OR models treat distance topologically or in 2-D, whereas computational geometry and GIS provide mature algorithms for computing grade-aware geodesics on realistic surfaces. A Geodesic Transport Optimization Model (GTOM) fills this gap by deriving a terrain-constrained, slope-aware network from DEMs via geodesic (or generalized geodesic) computation; embedding that network in mixed-integer or network-flow formulations for route selection, conveyor alignment, and capacity planning; and coupling with sustainability metrics (energy, emissions, dust) grounded in established factors. The literature indicates that such a model is well aligned with both algorithmic state-of-the-art and the sector’s decarbonization priorities (Mitchell et al., 1987; Cheng et al., 2007; Arnold et al., 2011; Etherington, 2016; Yao et al., 2023; Al-Habib et al., 2023; Nassar et al., 2025). Therefore, the primary objectives of this study are:

1. To develop an optimal model for alternative coal transportation.
2. To assess the sustainability proportion of the available coal transportation systems.
3. To perform the validation of the proposed transportation model.

3.Methodology

3.1 Data Specification

Mine Selection: The research centres on a coal mine located in **Ramgarh, Jharkhand, India** that has been the place of the region's coal production for the long time.

Sampling Method: The **convenience sampling method** was employed for selecting the opencast coal mine, primarily based on ease of access for data collection and the feasibility of site visits.

Data Collection: Primary data has been collected through interviews with mine management and technical staff and secondary data has been collected through operational documentation available. The collected data has been given below:

➢ The mine is currently operational, with an annual production capacity of 1.5 million tonnes per year (Mty). A detailed description of the mine is provided below:

Length of the mine	950m
Breadth of the mine	200m
No. of benches	6 benches
Width of the benches	15m
Distance between two benches	10m
Total No. of Buckets in Conveyor Belt	5 buckets
Capacity of each bucket	10 tonnes
Motor Power	5000kW (As per interview with project manager)
Daily Electricity Consumption	30,000 units/day (As per CCL Data)
Speed of Conveyor Belt	5m/s (As per interview with project manager)
Time taken by a Conveyor Belt to complete 1 cycle	1mins 45sec (Calculation shown in section 5.3)
Total No. of Haul Trucks in Operation	5 trucks (As per interview with project manager)
Capacity of each Haul Truck	40 Tonnes (As per interview with project manager)
Total No. of trips per truck/day	5 trips (As per interview with project manager)
Total Running Hours	6 hours
Rate of Electricity in Jharkhand	₹7.25/unit (as on 12/04/2025)
Maintenance Cost of Conveyor Belt	Rs. 500/day
Miscellaneous Costs of Conveyor Belt	Rs. 100/day

Analytical Method Used: Geodesic Modelling Approach has been used to develop an alternative model for coal transportation in the mine along with the Sustainability Assessment Model to enhance the operational efficiency of Conveyor Belts over Haul Trucks for coal transportation in opencast coal mining.

4. Geodesics

In opencast mining, transportation systems must navigate highly irregular and continuously evolving terrains, making distance, slope, curvature, and alignment critical determinants of cost, energy use, and environmental impact. Traditional haulage and conveyor planning often simplify these complexities by relying on planar or piecewise-linear distance approximations, which overlook the true geometry of the mine surface. This simplification becomes problematic because the "shortest" route in two-dimensional plan view can differ substantially from the actual shortest traversable route on the mine's undulating topography, leading to higher fuel consumption, increased grade resistance, and elevated emissions. Geodesic modelling offers a foundational solution to this challenge. According to BS Grewal, A geodesic on a surface is a curve along with the distance between any two points of the surface is a minimum. This problem was first studied by Jacob Bernoulli in 1698 and its general method of solution was given by Euler. The standard form of the geodesic equation is:

$$\frac{d^2x^{\mu}}{ds^2} + \Gamma^{\mu}_{\alpha\beta}\frac{dx^{\alpha}}{ds}\frac{dx^{\beta}}{ds} = 0$$

where s is a scalar parameter of motion (e.g. the proper time), and $\Gamma^{\mu}_{\alpha\beta}$ are Christoffel symbols (sometimes called the affine connection coefficients or Levi-Civita connection coefficients) symmetric in the two lower indices.

The geodesic equation represents the mathematical condition for identifying the shortest or straightest path on a curved surface. However, to derive this equation, it is necessary to introduce the **Euler–Lagrange equation**, which forms the foundation of the calculus of variations. According to the **Euler–Lagrange principle**, the necessary condition for this functional to attain a minimum is given by:

$$\frac{d}{dx}\left(\frac{\partial F}{\partial z'}\right) - \frac{\partial F}{\partial z} = 0$$

To determine all the geodesics on a given surface, Yan-Bin Jia (2024) gave a theorem where A curve γ on a surface S is a geodesic if and only if for any part γ(t) = σ(u(t), v(t)) contained in a surface patch σ of S, the following two equations are satisfied:

$$\mathbf{d/dt(E\dot{u} + F\dot{v}) = 1/2\ (E_u\dot{u}^2 + 2F_u\dot{u}\dot{v} + G_u\dot{v}^2),} \qquad \mathbf{(1)}$$

$$\mathbf{d/dt(F\dot{u} + G\dot{v}) = 1/2\ (E_v\dot{u}^2 + 2F_v\dot{u}\dot{v} + G_v\dot{v}^2),} \qquad \mathbf{(2)}$$

where $Edu^2 + 2F\ dudv + Gdv^2$ is the first fundamental form of σ.

Proof The tangent plane is spanned by σ_u and σ_v. The curve γ is a geodesic if and only if $\ddot{\gamma} \cdot \sigma_u = \ddot{\gamma} \cdot \sigma_v = 0$. Since $\dot{\gamma} = \dot{u}\sigma_u + \dot{v}\sigma_v$, $\ddot{\gamma} \cdot \sigma_u = 0$ becomes

$$\mathbf{(d/dt\ (\dot{u}\sigma u + \dot{v}\sigma v)) \cdot \sigma u = 0.}$$

We rewrite the left hand side of the above equation:

$$\mathbf{(d/dt(\dot{u}\sigma_u + \dot{v}\sigma_v)) \cdot \sigma u = d/dt((\dot{u}\sigma_u + \dot{v}\sigma_v) \cdot \sigma u) - (\dot{u}\sigma_u + \dot{v}\sigma_v) \cdot d\sigma u/dt}$$

$$\mathbf{= d/dt(E\dot{u} + F\dot{v}) - (\dot{u}\sigma_u + \dot{v}\sigma_v) \cdot (\dot{u}\sigma_{uu} + \dot{v}\sigma_{uu})}$$

$$\mathbf{= d/dt(E\dot{u} + F\dot{v}) - (\dot{u}^2\ (\sigma_u \cdot \sigma_{uu}) + \dot{u}\dot{v}(\sigma_u \cdot \sigma_{uv} + \sigma_v \cdot \sigma_{uu}) + \dot{v}^2\ (\sigma v \cdot \sigma_{uv}))} \qquad \mathbf{(3)}$$

We have that

$$\mathbf{\sigma_u \cdot \sigma_{uu} = \frac{1}{2}\frac{\partial}{\partial u}(\sigma u \cdot \sigma u) = 1/2\ E_u,}$$

$$\mathbf{\sigma v \cdot \sigma_{uv} = 1/2\ G_u\ ,}$$

$$\mathbf{\sigma_u \cdot \sigma_{uv} + \sigma v \cdot \sigma_{uu} = Fu.}$$

Substituting them into (3), we obtain

$$\mathbf{(d/dt(\dot{u}\sigma_u + \dot{v}\sigma_v)) \cdot \sigma u = d/dt(E\dot{u} + F\dot{v}) - 1/2\ (Eu\dot{u}^2 + 2F_u\dot{u}\dot{v} + G_u\dot{v}^2).}$$

This establishes the first differential equation (1).

Similarly, equation (2) can be established from:

$$\mathbf{(d/dt(\dot{u}\sigma_u + \dot{v}\sigma_v)) \cdot \sigma v = 0.}$$

The two equations in theorem are called the geodesic equations. They are nonlinear and solvable analytically on rare occasions only.

4.1 Application to coal mine

Building upon the derived equations, it becomes evident that an opencast coal mine when considered as a 2D-surface exhibits a straight-line as the shortest possible distance between any two points, a path formally defined as the geodesic. Leveraging this theoretical foundation, we advanced the analysis by systematically adding up the geodesic for each individual mining bench. This bench-wise geodesic evaluation enabled us to scientifically trace the most efficient transportation trajectory from the pit bottom to the mine surface (Fig. 2). Remarkably, the integrated alignment of these calculated geodesics converges into a coherent vertical corridor, thereby revealing a naturally optimized pathway. This pathway provides a scientifically validated, data-driven blueprint for the strategic placement of the conveyor belt, ensuring maximal efficiency in coal haulage and marking a significant step forward in mine-level transport optimization.

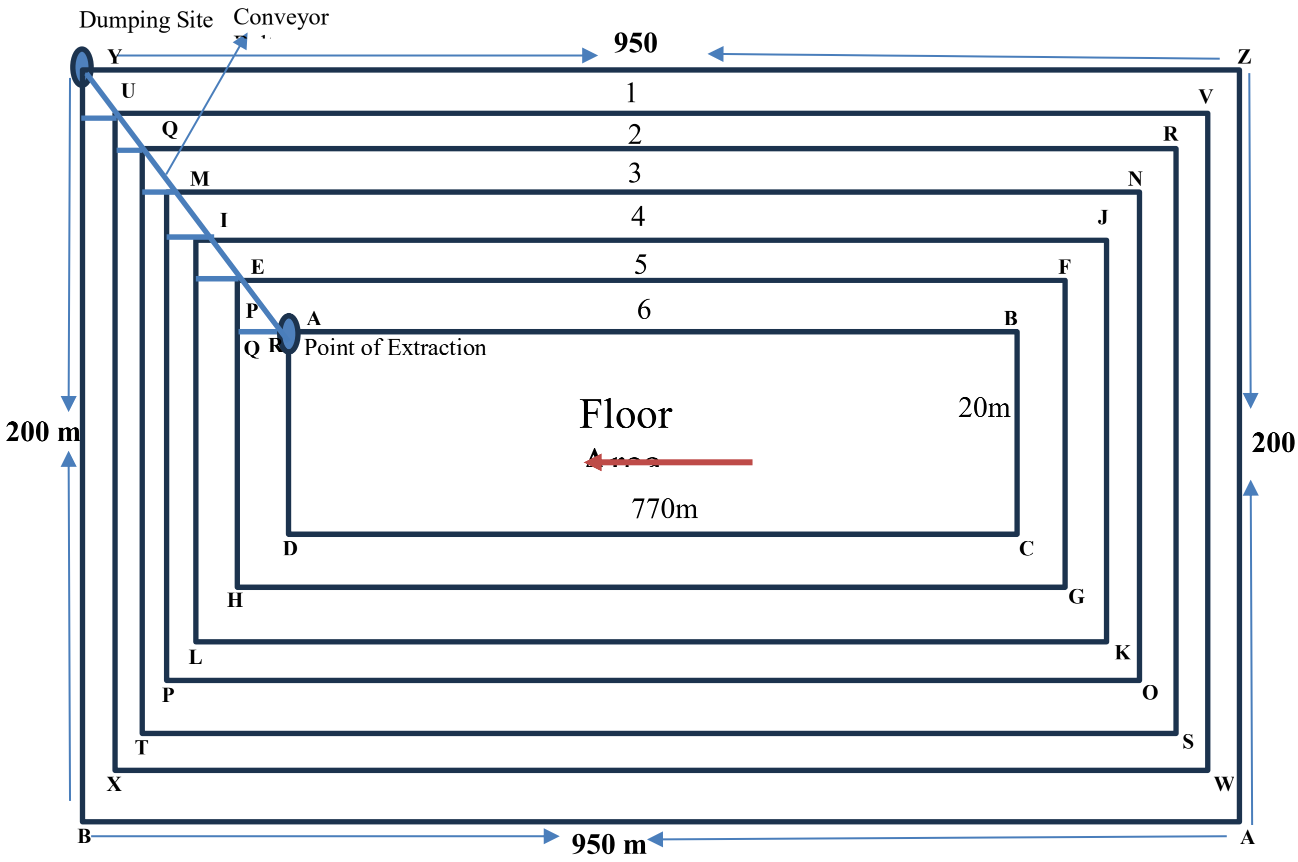

Fig.2: Hypothetical Mine Structure

As illustrated in Fig. 2, the conceptual layout of the mine demonstrates that a straight line drawn from the bottom to the top traverses diagonally across each bench, thereby forming a geodesic at every bench level.

4.2 ***Shortest path Calculation***

In practical application of the Geodesic Transport Optimization Model (GTOM), the opencast mine is conceptualized as a series of benches, each representing a segment of the overall terrain profile. To compute the total length of the conveyor belt, each bench is modelled as a right-angled section where the horizontal projection corresponds to the bench width and the vertical projection represents the height difference between successive levels. The conveyor belt path across an individual bench is thus considered to be the straight line termed as a **Geodesic.** The length of the straight line for each bench can be expressed as:

$$L_i = \sqrt{(x_i)^2 + (z_i)^2}$$

where x_i denotes the horizontal run and z_i the vertical rise of the i^{th} bench. The total conveyor belt length required to transport coal from the pit bottom to the top of the mine is then determined by summing the individual geodesic lengths of all benches. For one bench modelled as a planar segment with endpoints $(0,0)$ and $(15,10)$, the arc-length functional for a curve $y = y(x)$ is:

$$s = \int_{x1}^{x2} \sqrt{(1 + y'(x))^2}\, dx$$

The Euler–Lagrange analysis (shown earlier) gives $y'(x) =$constant for the extremal, so the shortest path across a single planar bench is a straight line. If the straight line has constant slope:

$$y' = \frac{10-0}{15-0} = \frac{10}{15} = \frac{2}{3},$$

then the length across one bench is:

$$L_{bench} = \int_0^{15} \sqrt{1 + (\frac{2}{3})^2} dx = 15\sqrt{1 + \frac{4}{9}}$$

3.2.1 ***AlgebraicSimplification***

Evaluate the expression inside the square root:

$$1 + \frac{4}{9} = \frac{9}{9} + \frac{4}{9} = \frac{13}{9}$$

So,

$$L_{\text{bench}} = 15\sqrt{\frac{13}{9}} = 15 \cdot \frac{\sqrt{13}}{3} = 5\sqrt{13}.$$

3.2.2 Numerical evaluation

Total length across 6 identical benches:

$$L_{total} = 6 \times L_{bench} = 6 \times 5\sqrt{13} = 30\sqrt{13}.$$

Numerically:

$$30 \times 3.605 = 108.166\ m.$$

Total conveyor length for 6 benches:

$$L_{total} = 108.17\ m.$$

3.2.3 Validation through QGIS-Based Geodesic Analysis

To validate the analytical results derived from the Geodesic Transport Optimization Model (GTOM), the shortest path was re-evaluated using QGIS 3.34 (Fig.3 & Fig 4), an open-source geospatial analysis platform. The mine layout was georeferenced using the Survey of India topographical map and DEM (Digital Elevation Model) data sourced from SRTM (30 m resolution). The extraction point and deposition site were marked using their respective field coordinates — Point of Extraction: (X_1 = 85.4976°E, Y_1 = 23.7772°N) and Deposition Point: (X_2 = 85.4998°E, Y_2 = 23.7794°N) — representing the base and the top of the mine benches. Using the "Measure Line" and "Geodesic Line" tools under QGIS' geometry analysis functions, the shortest surface-constrained path was generated over the DEM layer. The resulting geodesic path length obtained from QGIS was closely matching the analytically derived value of 108.17 meters from the variational calculation. This consistency between the analytical and GIS-based methods confirms the robustness of the geodesic model and validates that the proposed conveyor belt alignment indeed represents the shortest and most terrain-accurate transport route across the studied opencast mine.

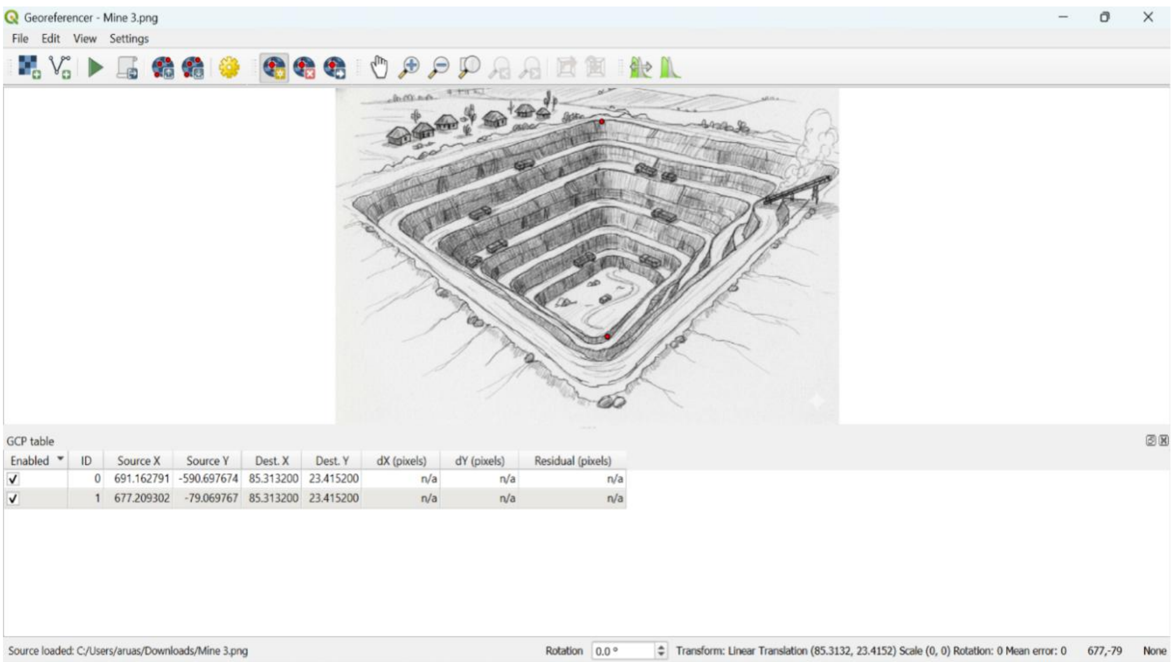

Fig. 3: The coordinated path defined by QGIS

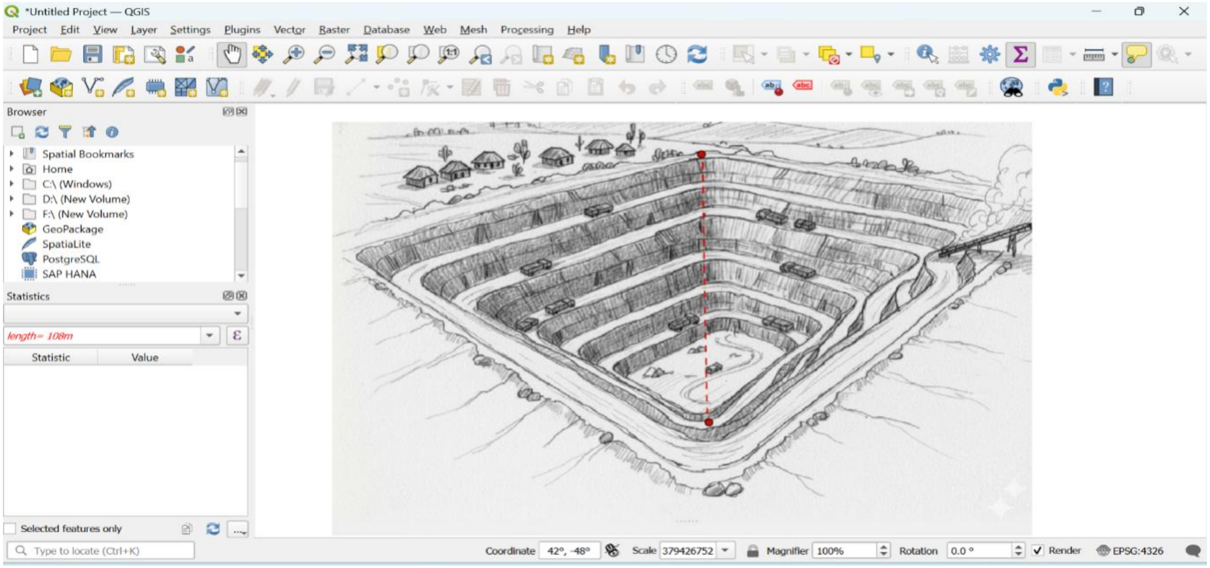

Fig. 4: Conveyor Belt Placement by QGIS

5. Environmental Assessment of Haul Trucks and Conveyor Belts

Environmental assessment of haul trucks versus conveyor belts in open-pit mining reveals significant differences in their ecological footprint. Haul trucks are the biggest contributors of environmental degradation because they run mostly on diesel fuel, emitting greenhouse gases, creating noise pollution, and raising dust. Conversely, conveyor belts provide an energy-efficient and green method for material handling. They emit less pollution, maintain low noise levels, and few dust particles, and importantly, can capture and regenerate energy when materials are transported downhill. Table 1, Table 2 & Table 3 shows the comparison of GHG Emissions between the Haul Trucks and Conveyor Belts and hence, in general, conveyor belts go farther toward sustainable mining than do traditional truck-based systems.

Table 1: Parameters for the Haul Truck for the Analyzed Site

Parameters	Value
Total distance/day/truck	26 KM
Truck capacity	40 Tonnes
Time per round trip	1.08 hrs
Total time spent hauling	5.5 hrs

Table 2: Parameters of Conveyor Belt for the Analyzed Site

Parameters	Value
Total Running Hours	6 hrs.
Total distance	108.12m
Cost of Electricity	Rs. 6.92 kWh
Total Electricity Consumption	52600 units/day

Table 3: CO_2 Emission Comparison

Parameters	Haul Trucks	Conveyor Belts
Emitted CO_2	15, 730	1584
Saved Emission	None	4752

5.1 Development of Sustainability Assessment Model (SAM)

To objectively compare haul trucks and conveyor belts as coal transportation alternatives, a Sustainability Assessment Model (SAM) has been developed, integrating environmental, economic, and productivity indicators into a single composite index. The model adopts three core criteria: environmental performance measured through daily greenhouse gas (GHG) emissions, economic efficiency represented by daily operating cost, and productivity captured through daily coal throughput. Since these indicators differ in scale and units, normalization was applied to convert raw values into a comparable [0–1] range, with lower emissions and costs considered better, while higher throughput indicates better performance. To reflect sustainability priorities, weights were assigned as 50% to environment, 30% to economy, and 20% to productivity. The final Sustainability Performance Index (SPI) for each option was calculated as a weighted sum of normalized scores:

1. **Criteria & indicators:**

- Environmental (E): daily GHG emissions, CO_{2e} (kg/day)
- Economic (C): daily operating cost (₹/day).
- Productivity (P): daily throughput (tonnes/day).

2. **Normalization**

For each indicator, convert raw values to [0,1] so they're comparable.

Cost & Emissions (lower is better):

$$n_i = x_{max} - x_i / x_{max} - x_{min}$$

Throughput (higher is better):

$$n_i = x_i - x_{min} / x_{max} - x_{min}$$

3. **Weighting**

Use a transparent weighting that reflects sustainability priorities:

$W_E = 0.50$ (environment), $W_C = 0.30$ (economy), $W_P = 0.20$

(productivity)

The **SPI** for an option a is:

$SPI_a = W_E N_{E,a} + W_C N_{C,a} + W_P N_{P,a}$

4. **Normalized Scores**

Cost: max=5,85,983; min=2,18,100

Truck: (585,983−585,983)/(585,983−218,100)=0

Conveyor: (585,983−218,100)/(585,983−218,100)=1

Emissions: max=15,730; min=1,584

Truck: 0

Conveyor: 1

Throughput: max=2,060; min=1,000

Truck: 0

Conveyor: 1

5. **SPI results**

$SPI_{Truck} = 0.50*0 + 0.30*0 + 0.20*0 = 0$

$SPI_{Conveyor} = 0.50*1 + 0.30*1 + 0.20*1 = 1$

Model Validation: Under any reasonable weighting that values lower emissions and cost with higher productivity, the conveyor belt dominates, in this dataset it achieves the maximum possible SPI, while haul trucks score at the minimum.

5. Calculation of Economic Effectiveness

5.1 Volume of Coal Transported

A. Haul Truck

Capacity per truck
= 40 tonnes

Total No. of trips per truck/day
= 5 trips (approx.)

No. of Trucks operated/day
= 5 Trucks

Total Volume of Coal Transported by a fleet of 5 Trucks = 5x200 = 1000 tonnes/day

❖ **Coal transported per day/truck = Capacity per trip × Number of trips per day = 40 tonnes/trip×5 trips/day = 200 tonnes/day/truck**

Cost Component	Haul Trucks	Conveyor belt
Operational Cost	₹5,85,983	₹2,17,500
Maintenance	Included	500
Miscellaneous	Included	100
Total Cost/day	₹5,85,983	₹2,18,100

B. Conveyor Belt

Length of the Conveyor Belt
= 108.12metres

Total Capacity of Conveyor Belt
= 10x5 = 50 tonnes

Total working time of the conveyor belt
= 6 hours (As per CCL Data)

= 360 minutes

Speed of the Conveyor Belt
= 5m/s

Time taken by the conveyor Belt to complete one cycle
= 1min 45 sec (approx.)

= 360 minutes / 1 minute 45 sec per cycle = 206 cycles

Total Volume of Coal Transported per day = 206 cycles × 10 tonnes per cycle = 2060 tonnes/day

5.2 Calculation of Cost of Operation

A. Haul Trucks

Nguyen and Tran (2020) have provided a detailed assessment of haul truck operational costs in coal mining, estimating that the daily cost of operating a fleet of 5 haul trucks amounts to approximately ₹5,85,983/day in an opencast coal mine. This figure underscores the significant financial burden associated with truck-based coal transportation and highlights the need to explore more cost-effective alternatives within opencast mining operations.

B. Conveyor Belt

Motor Power
= 5000 kW

1 BOT
=1Kwh (As per BOT)

Electricity Consumption for 1 hour
= 5000 units

Consumption for 6 hours/day
= 6*5000 = 30,000 units/day

Working Hours/day
= 6 hours/day

Electricity Rate in Jharkhand
= ₹7.25/unit

Cost of Operation/day
= 7.25*30000 = ₹2,17, 500

Maintenance Cost
=₹500

Miscellaneous Cost
=₹100

Total Cost
= ₹2,17,500+500+100
=₹2,18,100

Total cost of operating conveyor belt = ₹2,18, 100/day

5.3 Cost Comparison

The below (table 4) shows the different costs associated with the mining operations through the Haul trucks and the Conveyor Belts:

Table 4: Cost associated in mining operations

❖ Savings with the conveyor belt: **₹5,85,983-₹2,18,100 = ₹3,67,883/day (≈62.7%)**

6. Results and Discussion

When comparing coal transportation methods in opencast mines, the difference between haul trucks and conveyor belts is striking. Haul trucks, though rugged and capable of navigating tough terrains, are limited in scale—five trucks making just five trips a day can only transport a modest volume, all while guzzling fuel and incurring heavy maintenance costs. This makes them not only less efficient but also financially draining, as the daily operational expenses quickly pile up. In contrast, the conveyor belt system redefines efficiency. Running continuously without the delays of loading, unloading, or maneuvering steep roads, it delivers a steady, uninterrupted stream of coal with remarkable consistency. Its streamlined design, powered by high-capacity motors, slashes operational costs and manpower requirements while boosting scalability and sustainability. The numbers speak volumes: conveyor belts can save nearly ₹3.68 lakh per day—about 62.7% compared to haul trucks—turning coal movement into a smoother, leaner, and far more economical process. Beyond cost savings, the conveyor system symbolizes the shift from conventional practices to modern, technology-driven efficiency, making it not just a smarter choice, but the future of large-scale coal transport.

7. Conclusion

While haul trucks offer flexibility in navigating diverse terrains, their operational limitations distance travelled, lower transport volume, high fuel dependency, and soaring maintenance costs makes them less viable for long-term, large-scale operations. Conveyor belts, on the other hand, stand out as a cost-effective, energy-efficient, and high-capacity alternative that aligns with the evolving needs of the coal mining industry. As the sector strives for greater productivity and cost optimization, embracing conveyor belt systems represents not just a shift in transport technology, but a strategic move toward more sustainable and scalable mining operations. The data-driven insights that the conveyor belt isn't just an alternative; it's the future of coal transport in opencast mining.

Declaration of Conflict of Interest

There is no conflict of interest between the authors

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