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A Proposed Risk-Based Framework for Managing Consumer Trucks in Opencast Coal Mines

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A Proposed Risk-Based Framework for Managing Consumer Trucks in Opencast Coal Mines

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Abstract

Consumer (road-sale) trucks make brief visits to opencast coal mines, where they share roads, loading areas, and yards with heavy earth-moving machinery (HEMM), mining vehicles, and other pedestrians. This study proposes a site-adaptable framework for managing the movement of people from the entry to the exit. A targeted documentary synthesis of Indian mining regulations and technical circulars, relevant research, and occupational safety guidance informed a six-stage control sequence, an eleven-task hazard register, role assignments, stop-work criteria, ten proposed indicators, and five bowtie analyses. The framework integrates entry, travel, loading, weighing, covering with tarpaulin, and exit controls and links the proposed barriers to records for verification. The risk ratings are illustrative of the authors' judgments. For fatality-capable scenarios, the consequence score is retained after controls, and the lower likelihood ratings express intended control states only and do not demonstrate a measured risk reduction. The documentary search was not systematic, and the framework has not been validated with stakeholders or tested in the field. Mines must confirm the legal applicability and validate the controls and ratings against local conditions before their use.

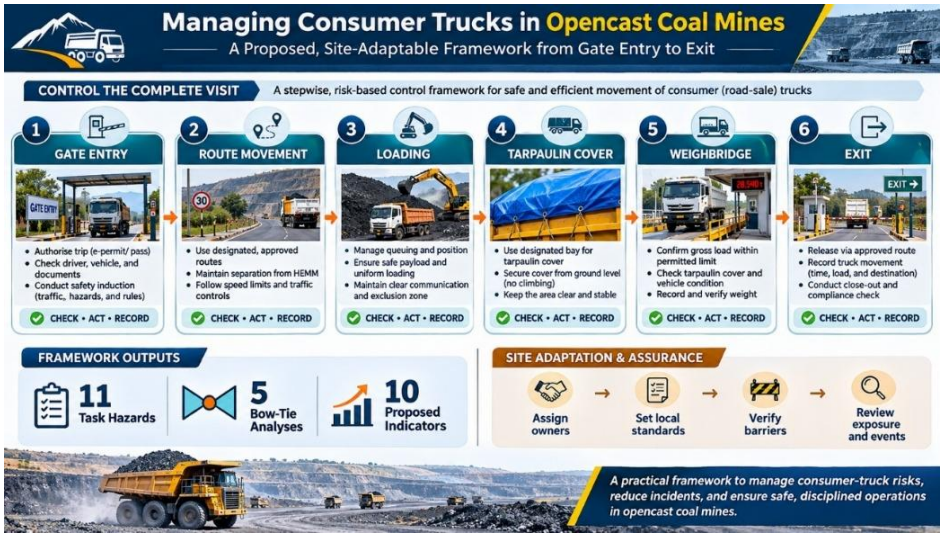


Figure Proposed lifecycle framework for managing visiting consumer trucks in opencast coal mines. Six movement stages connect the task hazards to the proposed controls, responsible roles,

and verification records. The hazard register, bow-tie analyses, and indicators are conceptual outputs for site adaptation and validation.

Keywords: consumer trucks; critical controls; mine traffic; opencast coal mines; risk assessment; transport management

1. Introduction

Trucks and other mobile equipment are persistent sources of serious injuries in surface mining. Analyses of fatal and non-fatal accidents in United States mines have identified haul trucks and other mobile equipment as the principal equipment types involved (Kecojevic et al. 2007; Ruff et al. 2011; Dindarloo et al. 2016), and studies of truck-related fatalities in surface mining have examined causal pathways and proposed intervention strategies (Zhang et al. 2014; Zhang and Kecojevic 2016). Reviews and injury severity analyses of heavy machinery and earthmoving equipment in other sectors also emphasise the need to manage the interaction between machines and people on foot (Kazan and Usmen, 2018; Duarte et al., 2021).

In India, accident analyses of mobile machinery in opencast coal mines (Kumar and Ghosh 2014) and hazard identification and risk assessment of opencast transport systems (Pandey and Mishra 2023; Sahu et al. 2023) have documented transport-related hazards, and hazard identification has been applied more broadly to Indian coal mines (Tripathy and Ala 2018). Limited visibility around large pieces of equipment is a recurring concern. Radio-frequency identification and radar systems have been examined as means of warning drivers of nearby vehicles and workers on foot (Ruff 2001; Ruff and Hession-Kunz 2001). A rapid review has summarised collision-avoidance and warning technologies for mining haul trucks (Hrica et al. 2022), and an analysis of serious and fatal collisions between mobile equipment and pedestrian workers has examined the role of proximity detection devices (Burlet-Vienney et al. 2026). Backing cameras and proximity alert systems have also been studied in construction work zones (Teizer et al. 2010; Ferreira et al. 2017). The NIOSH has published recommendations for evaluating and implementing proximity warning systems on surface mining equipment and a research roadmap for haul trucks (Ruff 2007; NIOSH 2020).

Road and driver-related factors are important considerations. Benchmarking of haul road design standards (Thompson et al. 1998) and full-scale testing of dump-point safety berms (Giacomini and Thoeni 2015) address road geometry and edge protection, while a review of the link between fatigue and safety and a study of fatigue drivers among haul-truck drivers address driver conditions (Williamson et al. 2011; Talebi et al. 2022). Studies of external goods vehicles have shown further hazards relevant to road-sale trucks: drivers are exposed to injury during loading and unloading and when covering loads with tarpaulins, and overloading is associated with injury severity in truck crashes (Shibuya et al., 2008; Shibuya et al., 2010; Marshall and Wells, 2011; Wen et al., 2022). These studies are from the fields of transport and logistics rather than mining, and they are used here to indicate hazard types and not the frequency of such events in the mines.

Most mining studies have focused on mine-owned fleets operated by trained employees in the production system. Consumer trucks differ from mine-owned fleets in that their drivers and maintenance arrangements are largely outside the system, their visits are brief, the drivers may be

unfamiliar with mine routes and signals, and the trucks must be loaded, covered, weighed, and dispatched within the operating area of the mine. In the sources reviewed, no framework dedicated to managing consumer trucks inside opencast coal mines was identified; this statement refers to the sources reviewed and is not an exhaustive claim.

Indian accident records illustrate this risk. Typical fatal accidents reported in Indian opencast mines involve road sales, buyers, hired trucks, and other mineral-transport trucks operating within the mine areas. In coal mines, the DGMS records describe a driver being struck by a truck moving backward near a coal stock, a helper being run over while working at the rear wheel of a truck, and a person being crushed between trucks in a dispatch queue; a later case explicitly involved an empty road-sale truck running over a mine official in a parking yard. In non-coal mines, reported incidents include an external truck rolling back from a steep loading ramp, a hired limestone-transport truck overturning after a steering failure on a haul road, and loaded trucks striking people while reversing or travelling near stockyards (pp. 51–54, 275 in DGMS 2024; pp. 225–226, 229, 271 in DGMS 2025). The reports did not identify every vehicle as a consumer truck, and this study did not claim that any particular incident involved one unless a specific record supported it. The cases point to recurring hazards at loading and parking areas, during reversing and queuing, and on steep or poorly protected haul roads, and they show that vehicle roadworthiness, safe movement, separation of pedestrians, and supervision must be managed together.

DGMS circulars describe fatal incidents involving wheeled trackless transportation machinery and draw attention to transportation rules, light vehicle routes, parking, and traffic management (DGMS 2024; DGMS 2025). These sources help identify hazards but do not establish the proportion of mining accidents involving consumer trucks. Therefore, the practical question is how a mine can control vehicles whose drivers and maintenance arrangements are outside the regular production system, even though their movements occur inside the mine's operating area.

This study makes a context-specific and integrative contribution by treating an externally managed truck visit as a complete operational lifecycle and connecting entry authorisation, loading, tarpaulin covering, weighing, exit, and assurance records. It does not propose a new safety theory or claim demonstrated effectiveness. It addresses three objectives:

- to identify the hazards and controls that apply to a consumer truck from gate entry to exit.
- to express them as a six-stage control sequence with defined roles, stop-work conditions, and records; and
- to link hazards, controls, and verification evidence through a task risk register, performance indicators, and bowtie diagrams.

Section 2 defines the scope and terminology; Section 3 summarises the regulatory and technical basis; Section 4 describes the methods. Section 5 presents the proposed framework. Section 6 discusses its application, comparison with the literature, and limitations. Sections 7 and 8 provide recommendations and conclusions, respectively, for future research. The framework supports mine-specific transport rules and operating procedures but does not replace statutory requirements or site-specific risk assessments.

2. Scope and Terminology

In this study, “consumer truck” refers to a road-going truck or tipper that enters an opencast mine to collect saleable coal, minerals, or other mine products. A typical visit includes travel from the entrance to an authorised loading point, movement to a weighbridge, and exit from the mine. The term describes the purpose of the vehicle in the transaction. It does not determine whether a vehicle is legally classified as an HEMM or which equipment-specific requirements apply. The mine should determine the applicability from the design, characteristics, and actual use of the vehicle, together with the relevant legal provisions, Gazette notifications, and DGMS directions. This paper covers movement within mine premises and public road operations after exit are governed by the applicable road transport requirements.

The framework is a documentary conceptual model. It has not been field-tested and does not establish universal speed limits, exclusion distances or residual risk values. Mines should adapt it to their traffic volume, operating hours, road geometry, vehicle dimensions and load, ground conditions, weather, loading arrangements and current statutory requirements.

3. Regulatory and Technical Basis

The Coal Mines Regulations 2017 provided the principal regulatory basis for this study. Regulation 109 requires transport rules suited to the machinery and prevailing mine conditions, along with effective communication and enforcement. Regulation 63 sets out the duties of the authorised operators of trucks, tippers, and dumpers, including pre-shift inspection, safe operation, audible warning, compliance with transport rules, and prevention of overloading or material projecting beyond the vehicle body (DGMS 2017). Mines should apply these provisions according to their wording, legal status, and the actual use of the vehicle.

Gazette notification G.S.R. 976(E), issued under Regulation 101, prescribes requirements for haul roads used by trucks and dumpers, including construction and maintenance suitable for vehicle load, traffic arrangements, road width, visibility, and gradient, subject to the conditions of the notification (Ministry of Labour and Employment 2018a). Notification G.S.R. 987(E), issued under Regulation 216(2), sets safety features and devices for HEMM, including specified trucks and tippers used in coal mines (Ministry of Labour and Employment 2018b). Mines should verify whether a given provision applies to a visiting road truck before treating it as an equipment requirement for that vehicle.

DGMS Technical Circular No. 03 of 2024 addresses accidents involving wheeled trackless transportation machinery in opencast coal mines and highlights transport rules, light vehicle routes, parking, and traffic management (DGMS, 2024). Technical Circular No. 07 of 2025 addresses the safety features and operating safeguards for HEMM and auxiliary equipment, including proximity and fatigue warning arrangements, route segregation, training, and standard operating procedures (DGMS 2025). Each circular should be used within its stated scope, alongside the current statutory requirements and later directions.

ISO 45001:2018 was used as a supporting reference for planning, implementing, checking, and improving occupational health and safety controls, including the hierarchy of controls; however, it does not replace Indian mining legislation (ISO 2018). NIOSH publications provide technical

context on equipment visibility, proximity warning systems, and haul-truck research priorities (Ruff, 2007; NIOSH, 2020).

4. Materials and Methods

4.1. Documentary Basis

This study used targeted documentary synthesis, not a systematic or scoping review. The evidence set comprised (i) primary legal and administrative sources: the Coal Mines Regulations, 2017, relevant Gazette notifications, and DGMS technical circulars; (ii) technical guidance: NIOSH publications and ISO 45001:2018; and (iii) peer-reviewed studies on mining and transport safety, proximity detection, haul-road design, fatigue, loading and tarping, risk matrices, and bow-tie methods. Official sources were used to identify stated duties and technical expectations; mining studies informed hazard pathways and control options; non-mining transport studies were used only to identify potentially relevant loading and tarping hazards. Bibliographic details of cited journal articles were checked against Crossref records. The contemporaneous search log was not retained; therefore, database names, exact query strings, search dates, screening totals, and exclusion counts cannot be reported, and source selection cannot be reproduced as a formal review. No formal quality appraisal was applied. The absence of a dedicated framework is consequently limited to the sources identified for this study and is not an exhaustive finding.

The movement was divided into six stages, from gate entry to exit. The author mapped the source statements and reported incident pathways to these stages and consolidated the overlapping scenarios into 11 task hazards. Five bow-tie top events were selected by judgment because they involved potential fatal or serious consequences and represented recurring exposure across route movement, loading, reversing, covering, and dispatching. The source set did not provide a consistent incident denominator or consumer truck category; therefore, the hazards were not ranked by frequency. No independent coding, stakeholder panel, Delphi exercise, site walkthrough, or pilot validation was performed. Therefore, roles, controls, indicators, and bow-tie barriers are proposed design elements, and regulatory requirements are distinguished from conditional requirements and good practice proposals in Supplementary Table S1.

4.2. Risk Rating

An indicative 5 × 5 matrix was used to structure the author's judgments, with the risk score calculated as the likelihood multiplied by the consequence (Tables 1 and 2). Initial ratings describe the task before the proposed controls, and hypothetical post-control ratings show an intended post-control state under the assumption that specified controls are implemented and verified. These are not observed outcomes, calibrated estimates, or evidence of risk reduction. For scenarios that can credibly result in a fatality, the consequence score remains 5 after control; proposed controls are assumed to affect the likelihood, not the severity of the worst credible outcome. Other consequence scores are also retained unless a control demonstrably changes the credible consequence. This conservative worked example is illustrative and must be reassessed by a site team using local evidence. No inter-rater agreement or sensitivity analysis was available for this study.

Table 1. Likelihood and consequence scales used for the indicative risk rating

Score	Likelihood	Consequence
1	Rare: not expected in normal operation	Insignificant: no injury or damage
2	Unlikely: could occur but not anticipated in routine operation	Minor: first aid or limited damage
3	Possible: can occur under foreseeable conditions	Moderate: medical treatment, lost-time potential, material damage
4	Likely: expected repeatedly or when tasks are done without reliable control	Major: serious injury, permanent impairment, major damage
5	Almost certain: frequent or imminent	Catastrophic: fatality, multiple serious injuries, catastrophic loss

Table 2. Risk bands (likelihood × consequence) and the response expected for each band

Score	Band	Expected response
1–4	Low	The controls were monitored and were maintained.
5–9	Moderate	Implement and verify controls and monitor their continued effectiveness.
10–16	High	Senior supervisor review, additional controls, and active verification were performed before the study was conducted.
17–25	Extreme	Do not commence or continue until the risk is reduced and is authorised.

Mines define their own acceptance criteria for the use of explosives. Ratings are indicative, and the date, participants, and evidence should be recorded for each assessment.

Risk matrices have recognised limitations, including coarse resolution and inconsistent ranking (Cox 2008; Duijm 2015). Therefore, this matrix is a worked example, not a quantitative risk estimate or a validated prioritisation model. The controls identified as critical are those whose failure could permit a fatal or serious top event, and for which a field-verifiable performance standard can be specified. The mine should repeat the assessment with drivers, dispatchers, security, loading staff, contractors, and safety officials, document the rationale for each likelihood and consequence score, and test whether plausible changes in likelihood assumptions would alter control priorities.

4.3. Control Selection and Bow-Tie Analysis

Controls were selected using the hierarchy of controls in ISO 45001:2018, prioritising elimination and engineering measures such as layouts that avoid reversing before administrative controls or PPE (ISO 2018). Five bow-tie diagrams were prepared for the selected high-consequence scenarios. In each diagram, preventive barriers address threats before the top event, and mitigative barriers limit the consequences after it (de Ruijter and Guldenmund 2016; Reason 2000). A pass, trip record, briefing, or inspection form is evidence that a control was checked, not the control itself. The barrier register identifies the proposed control, intended performance, responsible function, verification, and evidence record. These assignments are design proposals and require site-level confirmation (Catala et al. 2024; Mello et al. 2025).

5. Results: The Consumer-Truck Management Framework

5.1. Lifecycle, Roles and Control Architecture

The framework treats the visit of a consumer truck as six consecutive stages: (1) gate entry and authorisation, (2) route movement, (3) queuing and loading, (4) reversing, (5) tarpaulin covering, and (6) weighbridge and exit. Four cross-cutting elements support these stages: breakdown and emergency response, stop-work conditions, training and records, and critical control verification. Figure 1 shows the sequence and indicates the sections of this paper that describe each stage and element of the study.

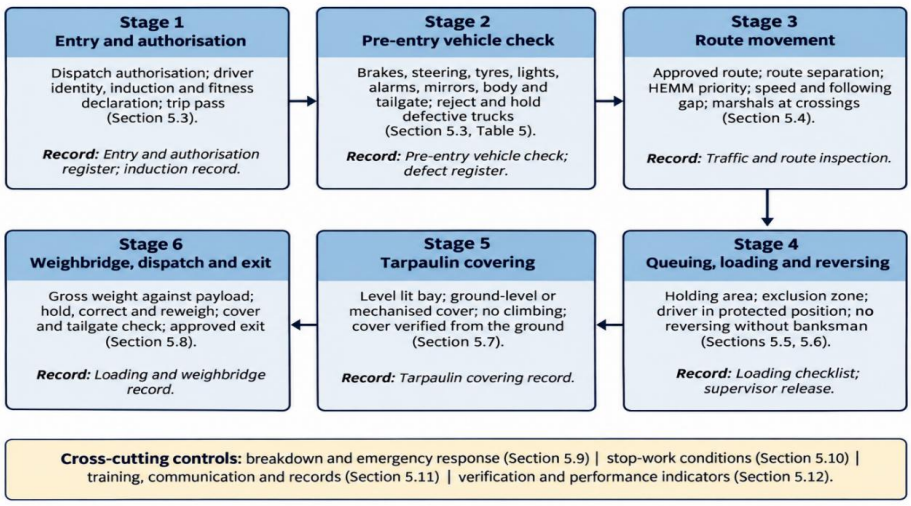


Figure 1. Six-stage movement sequence for a consumer truck in an opencast mine, with records generated at each stage and crosscutting control. Source: Author's framework.

Each stage depends on the assigned role. Table 3 summarises the responsibilities proposed for each role. They are written as functions rather than job titles so that a mine can assign them to its own organisation, and they complement the duties placed on the manager and authorised operators by the Coal Mines Regulations, 2017 (DGMS 2017).

Table 3. Roles and responsibilities proposed for the movement of consumer trucks

Role	**Responsibilities**
Mine manager or authorised official	The following measures were taken: approval of transport rules and procedures; ensuring suitable routes and loading areas; provision of trained staff and resources; approval of temporary route changes; suspension of truck traffic when critical controls fail; and review of incidents and corrective actions.
Security gate or entry inspector	Verify authorisation and documents; conduct the entry check; issue route and emergency information; deny entry for unresolved defects or unbriefed drivers; and maintain records.
Dispatch and weighbridge	Control trip release and queue sequence; maintain communication with loading and gate; verify gross weight and papers; prevent overloaded vehicles from proceeding; and log deviations.
Loading supervisor and loader operator	The identity and payload limit should be confirmed, the truck should be positioned safely, the exclusion zone and communication should be maintained, loading under unsafe conditions should be stopped, load security should be confirmed, and the signal should be released.

Traffic marshal or banksman	Control intersections, shared routes, and reversing; remain visible and outside blind spots; and stop traffic if communication is lost or the exclusion zone is breached.
Driver	Attend induction and briefing; declare fitness; use the approved route and speed; inspect the vehicle; wear the seat belt and personal protective equipment; obey signals; stop and report defects, unsafe conditions, incidents, and near-misses.
Fleet owner or contractor	Provide competent, authorised drivers and roadworthy vehicles; maintain documents; correct defects; communicate mine rules; and withdraw unsafe vehicles or drivers.

5.2. Task Risk Register

Eleven task hazards were identified, as illustrated in Figure 1. Table 4 lists the initial and hypothetical post-control ratings of each (likelihood × consequence, using Tables 1 and 2), the main controls with a pointer to the section that describes them, and the evidence that shows whether the controls are effective. Figure 2 shows the same ratings in a 5 × 5 matrix format.

Table 4. Task risk register for consumer trucks: initial and hypothetical post-control ratings, controls, and verification evidence. L, likelihood; C, consequence.

No.	**Task and hazard**	**Initial L × C**	**Main controls (section)**	**Residual L × C**	**Verification evidence**
1	Entry and authorisation: unauthorised or unbriefed driver; impaired or fatigued driver	3 × 4 = 12 (High)	Verify dispatch authorisation, documents and driver identity; induction in an understood language; trip briefing on route, restrictions, weather and contacts; fitness declaration and supervisor intervention; deny entry if concerns remain (5.3)	2 × 4 = 8 (Moderate)	Gate and dispatch logs; induction and briefing records; driver declarations
2	Vehicle defect: brake, steering, tyre, light, alarm, body or tailgate	3 × 5 = 15 (High)	Pre-entry safety-critical inspection; reject, tag and hold unsafe vehicles outside live traffic; repair and re-inspect; controlled recovery only (5.3)	2 × 5 = 10 (High)	Entry inspection; defect and rectification logs; release records

3	Shared-route collision with HEMM or another vehicle	3 × 5 = 15 (High)	Route separation; one-way flow; designated crossings and right of way; speed from the approved plan; marshal and communication at conflict points; no unauthorised deviation (5.4)	2 × 5 = 10 (High)	Route plan; traffic-control check; deviation and near-miss records
4	Runaway, fall over an edge or rollover	3 × 5 = 15 (High)	Road built and maintained to the applicable design; inspection of drainage, edge, surface, width and sight distance; approved route and suitable vehicle; restricted movement after rain or damage; no stopping at unsafe locations; emergency stop (5.4)	2 × 5 = 10 (High)	Road inspection; maintenance and closure logs; weather restriction records
5	Queue collision or person crushed between trucks	3 × 4 = 12 (High)	Holding area; spacing based on visibility and stopping distance; no standing between vehicles; stay in cab or protected place; marshal controls entry (5.5)	2 × 4 = 8 (Moderate)	Queue observation; briefing and marshal record
6	Truck and loader interaction: struck by bucket or falling material	3 × 5 = 15 (High)	Firm, level position; agreed signals; no swing until the truck is positioned; exclusion zone; no one under the bucket or on the vehicle; stop on lost communication or intrusion (5.5)	2 × 5 = 10 (High)	Loading checklist; supervisor release; incident and near-miss records
7	Overload, uneven load, unsecured tailgate or cover, spillage	3 × 5 = 15 (High)	Confirm payload; even loading with nothing above the sides; secure tailgate and cover; weigh every dispatch; correct overload in the designated area and reweigh (5.5, 5.8)	2 × 5 = 10 (High)	Load and payload records; weighbridge tickets; correction logs
8	Reversing collision or	3 × 5 = 15 (High)	Remove reversing by layout; designated zone; trained banksman in a visible, safe	2 × 5 = 10 (High)	Reversing-zone inspection; marshal

	pedestrian run-over		position; alarm and clear area verified; stop if contact is lost; no blind reversing (5.6)		observation; equipment checks
9	Dust, darkness, rain, fog, poor lighting or road blockage	3 × 4 = 12 (High)	Assess visibility and surface before release; maintain lighting and dust control; reduce or suspend traffic when stopping distance is inadequate; designated holding areas; restart after clearance (5.4, 5.10)	2 × 4 = 8 (Moderate)	Shift route briefing; weather and visibility log; closure and restart authorisation
10	Breakdown, fire, collision or spill exposing the driver or responders	3 × 4 = 12 (High)	Stop in a safe place; warning lamps; notify control room; protect the scene; keep people clear of traffic; trained recovery; fire response only if safe; preserve the scene (5.9)	2 × 4 = 8 (Moderate)	Emergency call logs; incident reports; recovery records; corrective actions
11	Tarpaulin covering: fall from height or struck at the cover point	3 × 5 = 15 (High)	Designated level, lit bay away from through traffic and the swing zone; ground-level or mechanised cover system, no climbing; truck stationary with parking brake on and ignition controlled; elevated access only from an assessed, protected platform by trained workers; supervisor or spotter with stop authority; no covering in rain, wind, darkness or poor visibility; cover verified from the ground (5.7)	2 × 5 = 10 (High)	Tarpaulin covering record; bay and cover-system inspection; loading and weighbridge records

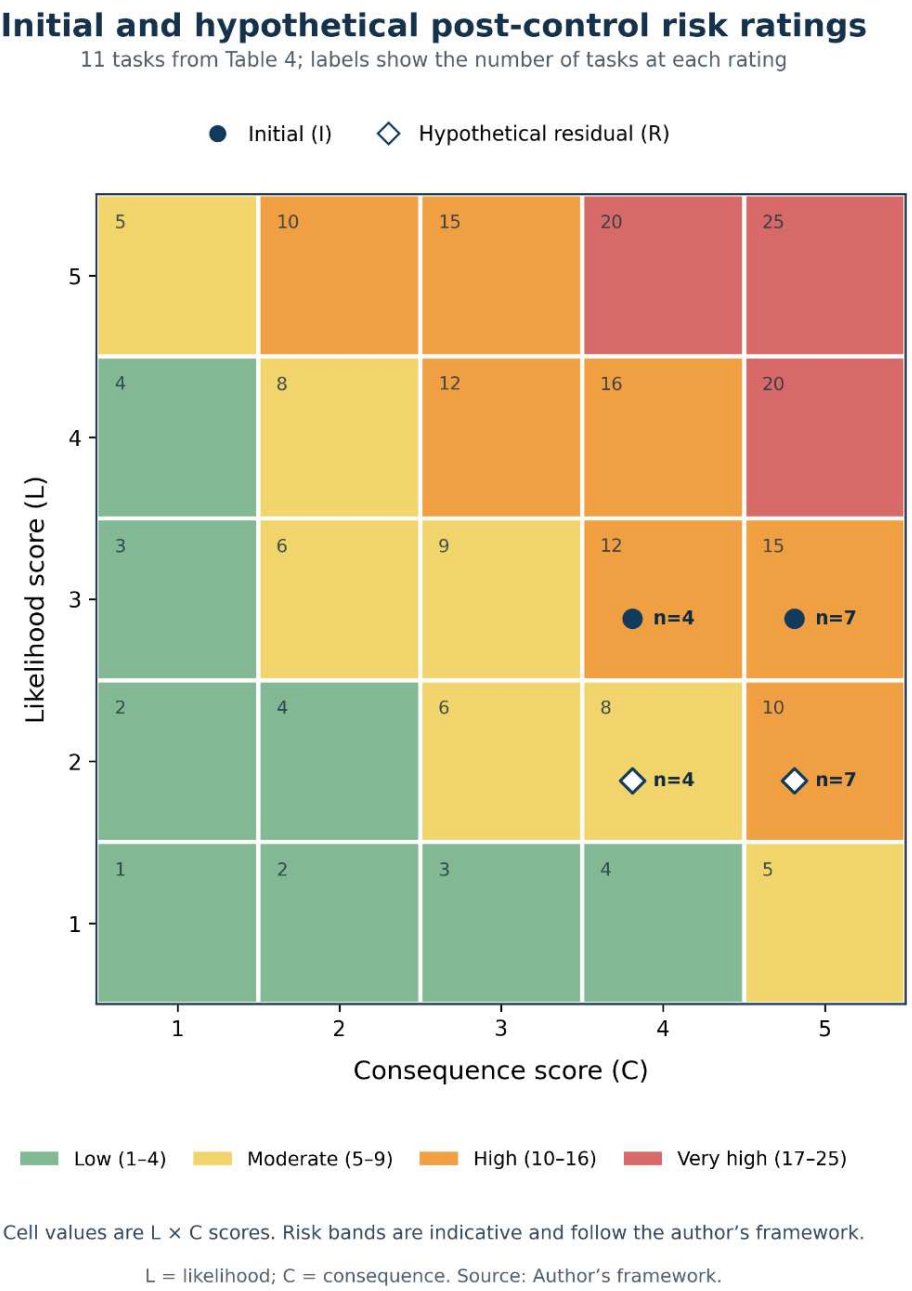


Figure 2. Indicative 5 × 5 risk matrix showing initial (I) and hypothetical post-control (R) judgments for the 11 tasks in Table 4. Source: Author 's framework.

The proposed post-control ratings remain high for fatality-capable hazards because the consequence score is retained at 5; the other hazards are shown as Moderate under the stated assumptions. This distribution is a conservative illustration of the intended control states, not a finding that risk has fallen. A high or moderate band does not establish acceptability; the site must apply its approved criteria, verify controls, and authorise work under its own risk-management process. No empirical reduction, comparative effectiveness, or implementation fidelity was measured.

5.3. Stage 1: Entry, Driver and Vehicle Controls

The gate is the only point at which the mine can stop an unsuitable driver or vehicle before it enters live traffic. The proposed sequence is:

(1) Dispatch confirms the authorisation for the trip (material, loading point, route, and time window); no dispatch is made to closed areas.

(2) The gate verifies the driver's identity, driving authorisation, entry permission, vehicle documents, payload, and tare.

(3) The gate confirms that the driver is alert and not impaired and refers any concern to the supervisor. Fatigue is a recognised risk for professional drivers (Williamson et al. 2011; Talebi et al. 2022), and DGMS circulars note proximity and fatigue warning arrangements for HEMM (DGMS 2025).

(4) The inspector carries out the pre-entry check listed in Table 5, covering service and parking brakes, steering, tires and wheels, lights, horn, mirrors and camera, reversing alarm, seat belt, windscreen and wipers, body and tailgate, leaks, and any statutory or manufacturer-specified features.

(5) Vehicles with defects that affect control, visibility, warning, occupant protection, or load retention are rejected, and the defect is recorded; no repairs are made in live traffic.

(6) Induction or briefing is given in a language that the driver understands, covering the route, speed, right-of-way, restricted areas, waiting locations, emergency contacts, weather and road status, and blasting or closure information.

(7) A trip pass or electronic authorisation is issued, and the entry time and releaser are recorded.

Table 5. Pre-entry check of safety-critical vehicle components. Each item is recorded as Pass, Fail, or Not applicable, with the defect and action noted.

Item	**What is checked**	**Reject and hold if**
Service and parking brakes	Brakes operate and the parking brake holds	Service brake ineffective, parking brake not holding, or fluid or air leak

Steering	Free movement and no visible leakage	Excessive play, stiffness or leak
Tyres and wheels	Condition and wheel fasteners	Cuts, bulges, exposed cord or loose wheel fasteners
Lights	Headlights, brake lights and indicators	Headlights or brake lights inoperative
Horn, mirrors and camera	Horn works; mirrors and any camera give the required view	Horn inoperative; mirror broken or view blocked; camera (if fitted) not working
Reversing alarm	Audible alarm operates when reversing	Alarm inoperative
Seat belt	Fitted and functional	Missing or not functioning
Windscreen and wipers	Clear view for the driver	Cracks in the driver's view or wipers inoperative
Body, tailgate and load retention	Body intact; tailgate and latches secure	Defective latch or body damage that could release the load
Leaks and visible defects	Fuel, oil or hydraulic leaks; loose parts	Leak or defect creating a fire or loss-of-control risk
Documents, authorisation and payload information	Valid documents; trip authorisation; tare and permitted payload recorded	Authorisation missing or invalid, or payload information absent

The inspector then records one of three decisions: accepted, rejected, or held for re-inspection. Before entry, the driver signs a declaration that they are authorised to drive the vehicle and have understood the briefing; will use the assigned route; are fit to drive; will follow instructions, wear the seat belt, obey signals, and not use a mobile phone; will stay within the payload; will report defects; and will stop if conditions are unsafe. Thus, entry into the mine is linked to documented authorisation, vehicle checks, and briefings, which support Regulations 63 and 109 of the Coal Mines Regulations, 2017 (DGMS 2017).

5.4. Stage 2: Route Movement

Between the gate and the loading area, the consumer truck shares roads with HEMM and mine vehicles. The proposed controls are:

- Only the designated route was used, and speed limits, signals, barriers, radio instructions, and marshals were obeyed. Site speed limits are set in the approved transport rules based on road geometry, payload, visibility, traffic, and stopping distance (DGMS, 2017; DGMS, 2024).
- Provide a physically separate route for consumers and light vehicles where practicable. If full separation is not practicable, use a site-assessed combination of protected crossings, physical channelisation where feasible, controlled time windows, one-way sequencing, a trained marshal at conflict points, reliable two-way communication, and suspend movement if these controls cannot be maintained. No entry to HEMM-only areas, active faces, dump zones, workshops, or fuel areas without authorisation and escort (DGMS 2024; DGMS 2025).
- Yield to HEMM and emergency vehicles, maintain a safe following gap, and do not overtake at bends, intersections, gradients, narrow roads, or loading zones.
- Wear a seat belt, do not use a mobile phone, and do not carry any unauthorised passengers or persons in the body.
- The vehicle should stop at a designated holding area if the conditions are inadequate and notify dispatch.

Road conditions are a control in their own right. Haul roads should be built and maintained to the applicable standard, with attention to width, gradient, drainage, visibility, and edge protection (Thompson et al. 1998; Ministry of Labour and Employment 2018a), and safety berms should be designed and tested for the vehicles that use them (Giacomini and Thoeni 2015). The inspection of drainage, edges, surface, and sight distance, and the restriction of movement after rain or road damage, are the main controls against runaway, edge fall, and rollover (Table 4, task 4). Dust, darkness, rain, and fog reduce visibility; the shift briefing should therefore include a visibility and surface assessment, and traffic should be reduced or suspended when the stopping distance is inadequate (Table 4, task 9).

5.5. Stage 3: Queuing and Loading

Queues and loading points concentrate the interactions between trucks, loaders, and pedestrians. The DGMS records described in Section 1 include a person being crushed between trucks in the dispatch queue (DGMS, 2024). Studies on truck driver accidents during loading and unloading describe hazard scenarios on and around the truck (Shibuya et al. 2010), and the proposed sequence addresses them as follows.

(1) The driver goes to the holding area and waits for the call, maintains spacing, and does not stand between the vehicles.

(2) The truck enters the loading zone only when authorised, follows signals, and stops on firm, level ground; no one stands under the bucket or in the swing zone.

(3) The parking brake is applied. The driver remains in the cab with the seat belt fastened or in a designated protected location, and never under a raised body or bucket.

(4) The supervisor verifies that the truck is stable and correctly positioned, that communication is working, and that all personnel are outside the exclusion zone.

(5) Only authorised material is loaded within the payload, evenly, and without anything projecting beyond the sides. Loading stops if the vehicle shifts or sinks, communication is lost, a person enters the exclusion area, or the body is damaged.

(6) Before release, the load is confirmed to be stable, the tailgate is secured, no one is on the vehicle, no material is hanging, the route is clear, and the release signal is given; the truck then proceeds to the tarpaulin bay for covering.

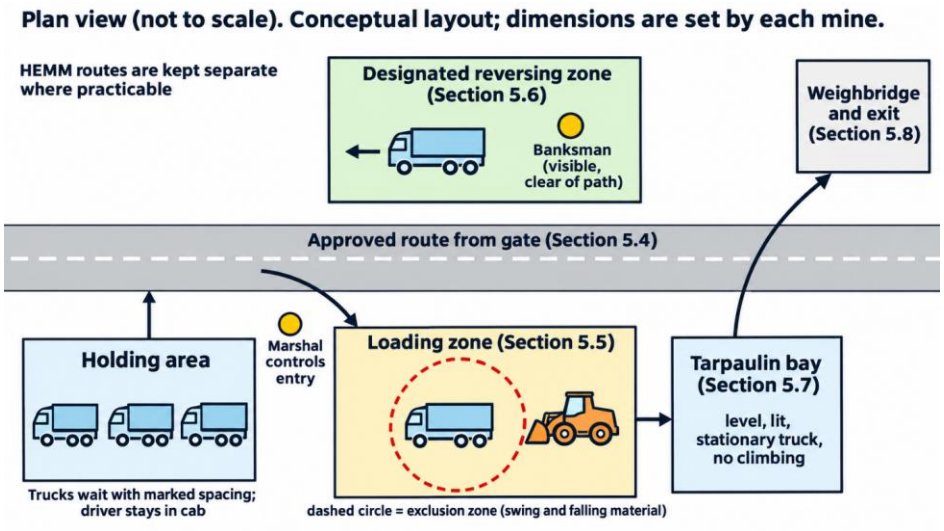


Figure 3. Conceptual plan view of the loading area for consumer trucks (not to scale), showing the holding area, loading zone, exclusion circle, tarpaulin bay, reversing zone, weighbridge, exit, and marshal and banker positions (Sections 5.4–5.8). Source: Author's framework.

5.6. Stage 4: Reversing

Reversing is a major cause of run-over accidents, and reports on proximity detection and backing cameras show that blind areas behind and around vehicles remain a concern, even when technology is available (Ruff 2001; Ruff and Hession-Kunz 2001; Teizer et al. 2010; Ferreira et al. 2017; Hrica et al. 2022; Burlet-Vienney et al. 2026). Therefore, the first control is to eliminate the reversal by layout. where it cannot be avoided:

- Reversing occurs in a designated area with a trained banksman who is visible to the driver, stands outside the path of the truck, and is aware of the blind area and swing radius. Communication signals were established during the induction process.
- The driver will stop immediately if the banksman is not visible, the instructions are unclear, the reversing alarm fails, or a person enters the work area.
- No one reverses unverified, verbal instructions. Self-reversing is permitted only when the layout has been designed, assessed, marked and authorised.

Proximity detection systems may supplement these controls where the mine adopts them, following the NIOSH recommendations for evaluating and implementing proximity warning systems (Ruff 2007); however, they do not replace a clear reversing area and trained banksman.

5.7. Stage 5: Tarpaulin Covering

Covering a load with a tarpaulin is a routine, but hazardous, task. Evaluations of tarping systems for flatbed trailers have examined the physical demands of the task (Marshall and Wells 2011), and studies on goods-transport drivers have described injuries during load handling (Shibuya et al. 2008; Shibuya et al. 2010). In a mine, this task increases exposure to traffic and the movement of loaders. The proposed sequence is as follows.

(1) First, confirm whether covering is required by an applicable legal or permit condition, the mine's dispatch rules, the material's containment or dust-control needs, or the receiving customer's documented requirement. If no such requirement applies, the mine records that covering is not required for the movement. When required, covering occurs at a designated bay after loading and before the weighbridge. The bay is level, firm, and lit, away from through traffic and the swing zone, with room for people to stay clear.

(2) Use a ground-level or mechanised system. No one should climb onto the body, wheel, tailgate, or load.

(3) Confirm that the truck is stationary, the parking brake is on, the engine is stopped or the key is controlled, and no one is in the path of the vehicle.

(4) Elevated access should be allowed only after a task risk assessment from a protected platform with a guardrail or fall arrest by trained workers.

(5) Assign a supervisor or spotter with the authority to stop work and defer covering in case of rain, strong wind, darkness, poor visibility, or when the load surface is unstable.

(6) Verify from the ground that the cover is secured, does not obstruct lights, mirrors, or the driver's view, and that the tailgate is secure; complete the record and release the truck to the weighbridge.

(7) Never stop on the haul road or at the exit to re-secure a cover; go to the bay or the nearest safe place. For a fall, injury, or collision, follow Section 5.9 and the stop-work conditions in Section 5.10.

5.8. Stage 6: Weighbridge and Exit

The weighbridge is the last verification point for payload and load security, and overloading is associated with greater injury severity in truck crashes (Wen et al. 2022). Regulation 63 of the Coal Mines Regulations, 2017 requires authorised operators to prevent overloading and projection of material beyond the body (DGMS 2017). The proposed sequence is

(1) The truck proceeds along the assigned route at the posted speed and follows the weighbridge operator's instructions.

(2) Gross weight is compared with the payload and authorisation. Overloaded or unevenly loaded trucks are held, directed to the correction area, relieved of excess material under supervision, and reweighed.

(3) Cover and tailgate security, absence of spillage hazard, and documentation were confirmed, and the vehicle, weight, destination, and time were recorded.

(4) The truck leaves only via the approved route, and security records the exit time.

5.9. Breakdown and Emergency Response

A truck that fails inside the mine can block a haul road, expose the driver to passing traffic, or start a fire; therefore, arrangements for a visiting driver must be simple and known before the driver's entry. The proposed rules, given in the briefing at the gate (Section 5.3), are as follows.

- If a brake, steering, tire, light, body, or load-security failure occurs, the driver stops at the nearest safe place, applies the parking brake, switches on the hazard lamps, notifies dispatch, and does not continue until authorised.
- Warning triangles or cones are placed only where it can be done safely. Repairs are not made at the roadside in a live operating area, and recovery is carried out only under an authorised arrangement.
- In the case of a fire, the driver safely stops the vehicle, switches off the engine if safe, evacuates, raises the alarm, and calls the mine emergency response; an extinguisher is used only by trained workers.
- After a collision, rollover, injury, near miss, or spill, the driver stops and secures the scene, raises an alarm, arranges first aid and emergency response, preserves evidence, and promptly reports the incident.
- In a blasting alert, severe weather, poor visibility, road failure, or blockage, the driver stops at a safe area, follows the instructions of the control room, and resumes only after authorised clearance.

These rules also provide the mitigative barriers of the bow-tie diagrams in Section 5.13 because they determine how quickly an event is detected, how the injury is limited, and how soon the route is restored.

5.10. Stop-Work Conditions

Every person involved in the movement of a consumer truck, including the driver, marshal, loading supervisor, weighbridge operator, and gate inspector, should have the authority and duty to stop the movement when a critical control measure is lacking. Stop-work authority is a recognised element of critical control management (Catala et al. 2024; Mello et al. 2025), and it counters dispatch pressure, which is identified as an escalation factor in Section 5.13. Figure 4 shows the decision flow, and the conditions are as follows: work resumes only after the condition is corrected and an authorised person confirms it.

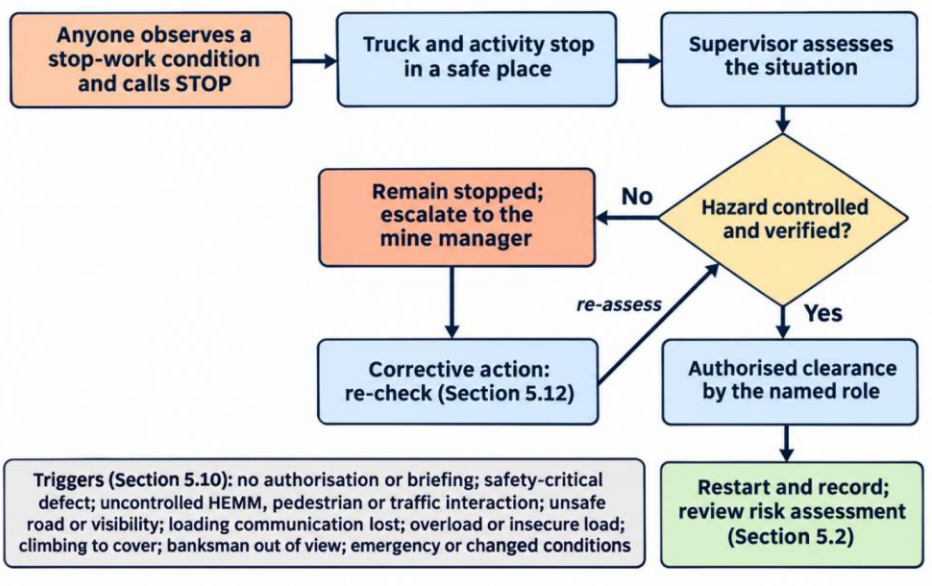


Figure 4. Stop-work decision flow for consumer truck movements. Source: Author 's framework.

- No current authorisation, briefing, or route information is available for the trip.
- Safety-critical defects exist in brakes, steering, tires, lights, warning devices, visibility, seat belts, and load retention.
- Interactions with heavy earth-moving machinery, pedestrians, or other traffic are not controlled, or the required marshalling is missing.
- The road surface, edge, gradient, water, dust, lighting, and visibility were deemed unsafe.
- Loading communication is lost, the vehicle is unstable, the exclusion zone is breached, or a person is in danger.
- The truck is overloaded, the load is insecure, the tailgate is defective, or the risk of spillage has not been addressed.
- Any person climbs onto the body or load to cover it, covering takes place outside the bay or with an unsecured truck, or the cover cannot be verified from a safe position.
- The banksman is out of view, the reversing alarm is inoperative, or the reversing area is not confirmed to be clear.
- An emergency, near-miss, route deviation, or changed condition renders the risk assessment unreliable.

5.11. Training, Communication and Records

The aforementioned controls work only if drivers understand them and if their application leaves evidence. Each driver should receive an initial induction before the first entry and a documented briefing for each trip or shift or whenever conditions change in a language that the driver understands. Driver competence is recorded, and the gate and loading staff are trained in the checks and stop-work rules that concern them. The need for training and communication of this

kind is consistent with the finding that haul-truck safety depends on drivers, supervisors, and the organisation (Zhang et al. 2014; Kazan and Usmen 2018).

Table 6 lists the nine proposed records, the responsible role for each, and the minimum content. Records are reviewed through risk-based field verification and monthly trend reviews, and the arrangements are revised after a significant incident, change of route or equipment, repeated non-conformance, or deterioration of the road or weather.

Table 6. Records proposed for consumer truck movements, responsible roles, and minimum content.

Record	**Responsible role**	**Minimum content**
Entry and authorisation register	Gate or dispatch	Vehicle and driver identity, authorisation, time in and out, approved route, and releaser.
Driver induction and briefing record	Training or dispatch	Date, language, topics, driver acknowledgement, briefer.
Pre-entry vehicle check	Gate inspector	Pass, fail, or not applicable for each item; defects; decisions; actions; inspectors; and re-inspection outcomes were recorded.
Defect and rectification register	Fleet owner or gate	Defect, hold date, repair, re-inspection, and release.
Traffic and route inspection	Designated supervisor	Route conditions, traffic control, deviations, reversal arrangements, and actions were also considered.
Loading and weighbridge record	Loading or weighbridge	Payload, gross weight, load condition, tailgate and cover check, corrections, and time were recorded.
Incident or near-miss report	Mine manager or safety official	The four components are events, causes, immediate actions, and reporting.
Audit and corrective-action log	Mine management	The findings, owners, due dates, and verification of closure are included.
Tarpaulin covering record	Loading supervisor or spotter	Bay, method, stationary truck confirmation, spotter, ground verification, and deferrals.

5.12. Critical-Control Verification and Indicators

A procedure is effective only if it has been verified to be so. Critical control approaches focus on a small number of controls, the failure of which would allow a major accident and require evidence that each control is present and functions as intended (Catala et al. 2024; Mello et al. 2025). The process-safety indicators of this type are a leading measure of whether safeguards are in place, whereas injury statistics are lagging measures of the outcomes (Hopkins, 2009; Reiman and Pietikäinen, 2012). Seven core critical controls were proposed for the consumer trucks.

- route authorisation and segregation from heavy earth-moving machinery
- haul-road and edge conditions;
- vehicle fitness;
- Safe loading and tarpaulin arrangements
- Separation of people and vehicles
- Payload and load security
- communication during reversing and emergencies.

Each control requires an owner, verification frequency, source of evidence, and defined response to failure. A failed control stops or restricts movement, and repeated failure triggers a review of the route design, arrangements, supervision, and transport rules. Table 7 lists the ten indicators with their type, frequency, and source records, and Figure 5 shows the cycle of recording, verification, review, and revision. Event counts should be normalised to exposure, for example, per 100 movements, and a low number of reported events should not be taken as proof that controls are effective, because under-reporting may conceal weak controls (Hopkins 2009; Reiman and Pietikäinen 2012).

Table 7. Indicators for verifying critical controls for consumer trucks

No.	**Indicator**	**Type**	**Frequency**	**Source record**
1	Entries with valid authorisation and recorded briefing (%)	Leading	Weekly	Entry register; induction record
2	Movements with completed safety-critical vehicle checks (%; site target 100%)	Leading	Daily or weekly	Pre-entry vehicle check
3	Movements on approved routes (%)	Leading	Weekly	Traffic and route inspection

4	Route deviations per 100 completed movements	Leading	Weekly	Traffic and route inspection
5	Overloading or load-security failures per 100 loaded dispatches	Leading	Weekly	Loading and weighbridge record
6	Loaded trucks with a verified secure cover (%)	Leading	Daily or weekly	Tarpaulin covering record
7	Reversing movements under approved arrangements (%)	Leading	Weekly	Traffic and route inspection
8	Critical-control failures found in inspections	Leading	Weekly	Inspection records
9	Near misses, collisions, overturns, injuries and damage cases	Lagging	Monthly	Incident or near-miss report
10	Corrective actions completed and independently verified by the due date (%)	Assurance	Monthly	Audit and corrective-action log

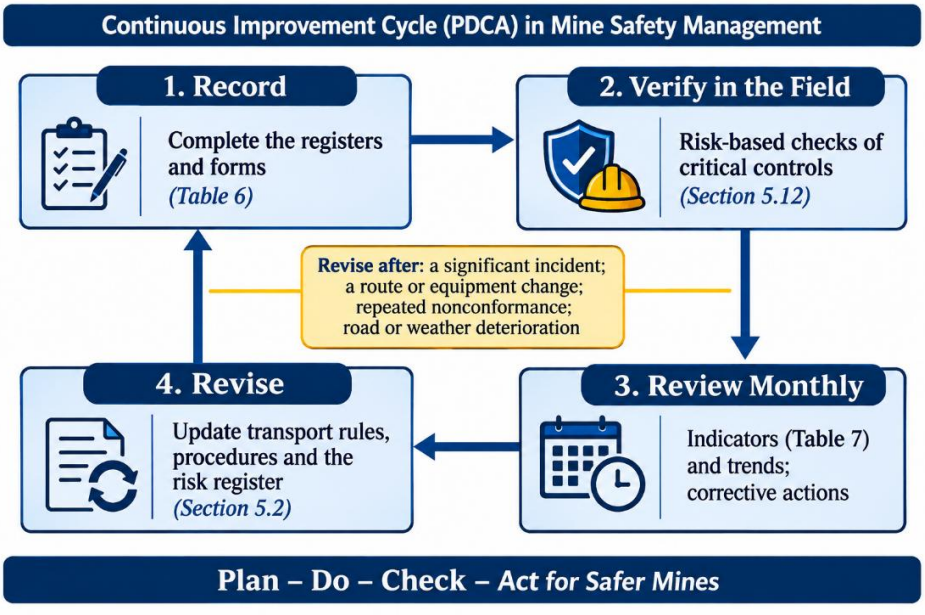


Figure 5. Record, verify, review, and revise cycle for critical controls. Source: Author 's framework.

5.13. Bow-Tie Analysis of Priority Top Events

The bow-tie method links the causes of a top event on the left with its consequences on the right and places preventive barriers between causes and the event and mitigative barriers between the event and its consequences (de Ruijter and Guldenmund 2016). Five top events were selected from the highest-consequence scenarios in Table 4 (Section 4.3). Table 8 summarises them, Figures 6 to 10 show the diagrams, and Table 9 lists every barrier with the section of this paper that describes it and the record that gives evidence of its performance. Each bow-tie has five preventive barriers (P) and three mitigative barriers (M), except the fourth, which has four mitigative barriers.

Table 8. Summary of the five bow-tie analyses

Bow-tie and figure	**Top event**	**Table 4 tasks**	**Main escalation factors**
BT1 (Figure 6)	Collision with heavy earth-moving machinery or another vehicle on a shared route	3, 5	Marshals absent at a crossing, blind areas of machinery, radio contact loss, and gate check bypassed.
BT2 (Figure 7)	Loss of control, rollover or fall over a road edge	2, 4, 7	Rain-damaged edges that were not inspected, trucks stopping on an edge or ramp, and delayed rescues.
BT3 (Figure 8)	Person struck or crushed during reversing, queuing or loading	5, 6, 8	Loading-speed pressure, banksman in a blind area, noise masking the alarm, and night or dust conditions.
BT4 (Figure 9)	Fall from height or struck by traffic while covering with a tarpaulin	11	Dispatch pressure due to slow covering, no bay or mechanised system, platform not assessed, and unauthorised assistance.
BT5 (Figure 10)	Overloaded, uneven or unsecured load, tailgate or cover failure, spillage	7, 11	Weighbridge calibration lapses, incentives to overload, and cover are considered optional.

5.13.1. Collision with Heavy Earth-Moving Machinery or Another Vehicle (BT1)

The first top event is a collision between a consumer truck and an HEMM or another vehicle on a shared route. Preventive controls include route authorisation, driver briefing, pre-entry fitness checks, visibility restrictions, route separation, and marshals at conflict points. A site speed limit and safe following distance are preventive controls that reduce the likelihood of collision; their potential to limit impact energy is secondary and must not be presented as an independent post-event barrier. Seat belts and emergency response are mitigative controls (Figure 6). Potential consequences include fatality or serious injury, vehicle or equipment damage, and reportable accidents.

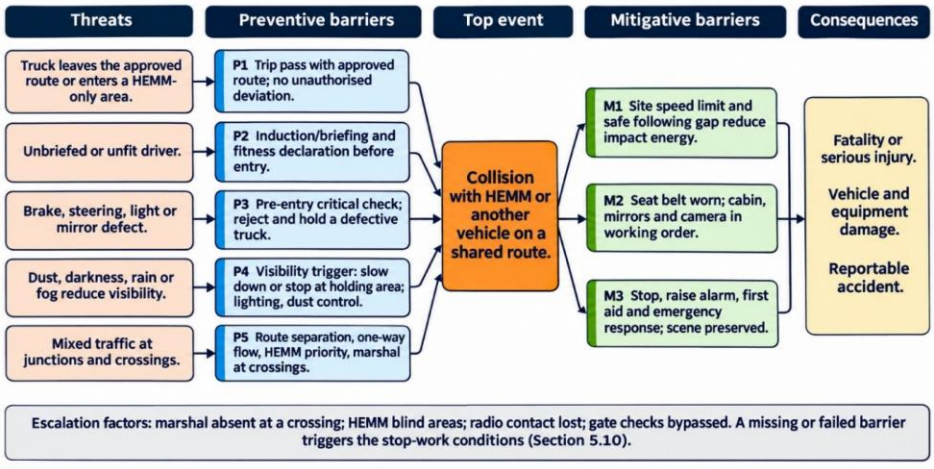


Figure 6. Bow-tie BT1: Collision with heavy earth-moving machinery or other vehicles on a shared route. P = preventive barrier, M = mitigative barrier. Source: Author's framework.

5.13.2. Loss of Control, Rollover or Fall over a Road Edge (BT2)

The second most common event was the loss of vehicle control, including rollover or departure over a road edge, potentially following brake, steering, or tire failure, overspeed, overload, or a wet road. Preventive controls include pre-entry inspection, fitness and speed management, road-edge and drainage inspection, payload control, and restrictions after rainfalls. Edge berms and road geometry are preventive measures, whereas seat belts, emergency response, and rescue arrangements are mitigation measures (Figure 7). The potential consequences include fatalities or serious injuries, vehicle loss, road blockages, fires, and spillage.

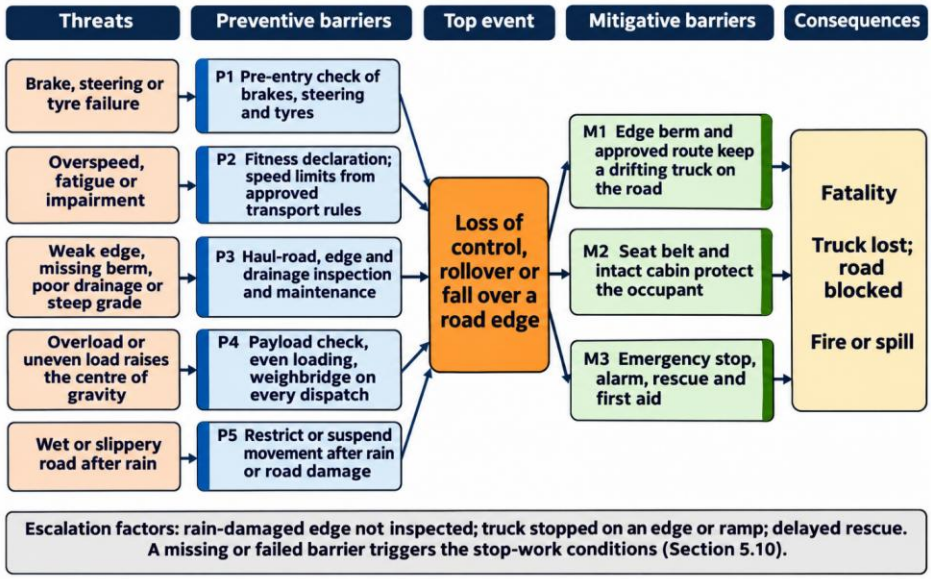


Figure 7. Bow-tie BT2: loss of control, rollover, or falling over the road edge. P = preventive barrier; M = mitigative barrier. Source: Author's framework.

5.13.3. Person Struck or Crushed during Reversing, Queuing or Loading (BT3)

The third most frequent event involved pedestrians close to moving trucks. Preventive barriers include a layout that avoids reversing, checks of the alarm, camera, and mirrors, keeping the driver in the cab, a holding area with marked spacing, and agreed signals with an exclusion zone around the loader (Figure 8). Mitigation consists of an immediate stop when the banksman is lost from view, marshal control of the area, and first-aid. The consequences are fatal run-overs or crushes, serious injuries, and accidents.

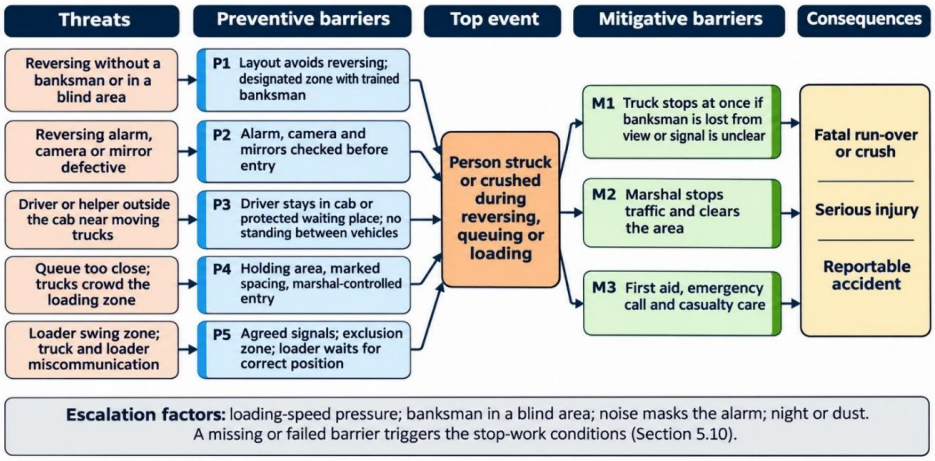


Figure 8. Bowtie BT3: Person struck or crushed during reversing, queuing, or loading. P = preventive barrier; M = mitigative barrier. Source: Author's framework.

5.13.4. Fall from Height or Struck by Traffic while Covering the Load (BT4)

The fourth top event was specific to the tarpaulin task. Preventive barriers are a ground-level or mechanised system with a ban on climbing, a designated bay away from through traffic, a stationary and controlled truck, deferral in adverse conditions, and no roadside re-securing. Mitigation applies where elevated access is unavoidable and relies on an assessed platform with fall protection, a spotter who can stop the work, ground verification of the cover, and emergency response (Figure 9). The consequences are a fatal fall, a worker struck by traffic, a loose cover that blocks the mirrors, and a reportable accident.

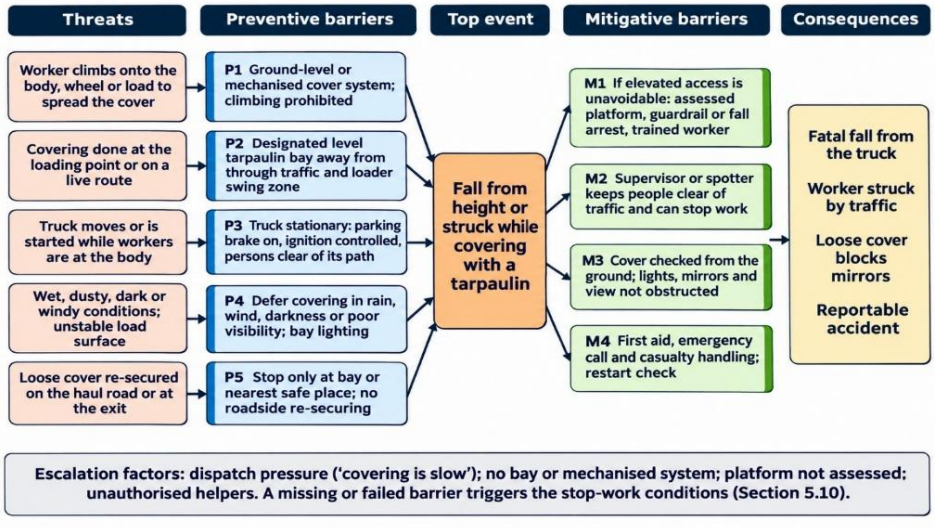


Figure 9. Bow-tie BT4: Falling from a height or being struck by traffic while covered with a tarpaulin. P = preventive barrier; M = mitigative barrier. Source: Author's framework.

5.13.5. Overloaded or Unsecured Load and Spillage (BT5)

The fifth top event covered overload, uneven loading, tailgate or cover failure, and spillage. Preventive barriers included confirmation of payload and tare at the gate, even loading with a release check, weighing of every dispatch, verification of the tailgate and cover, and the authority of any person to stop work. Mitigation included the removal of excess at a correction area, speed and route restrictions until the load was verified, and clearing of the spill with corrective actions (Figure 10). The consequences were loss of control or rollover, spillage that struck people, and regulatory actions.

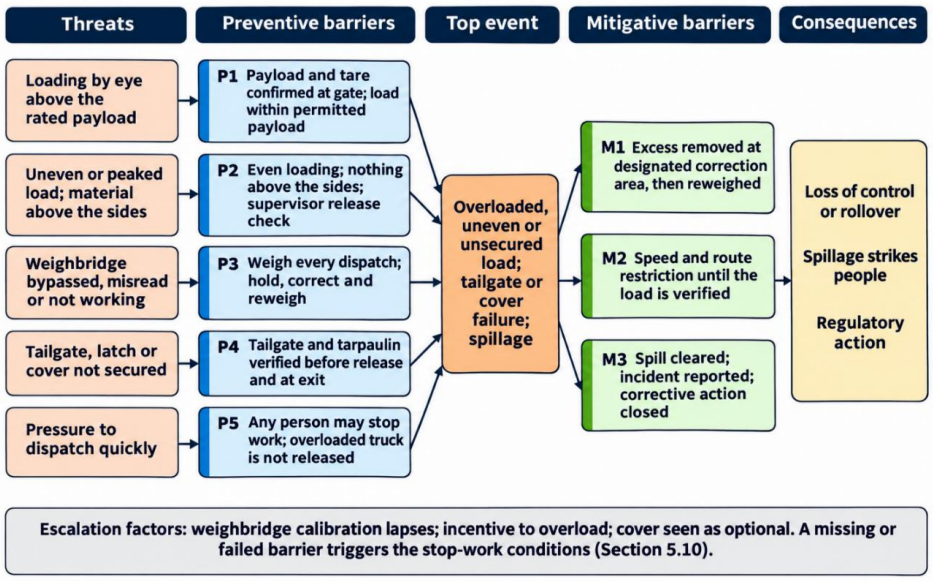


Figure 10. Bow-tie BT5: Overloaded, uneven, or unsecured loads, tailgate or cover failure, and spillage. P = preventive barrier; M = mitigative barrier. Source: Author 's framework.

The 41 bow-tie entries were proposed as controls rather than validated safeguards. A barrier is a physical, operational, or response measure, whereas a trip pass, checklist, briefing record, or audit entry is evidence of verification, not a barrier. P identifies a preventive function, and M identifies a mitigative function. A measure that can serve both functions should be classified based on the defined top event and its timing. The mine should assign each barrier to a named role, state a measurable site-specific performance standard, verify it at the stated frequency, and record the results. Table 9 provides the control references and evidence records for the local assignment.

Table 9. Barrier register for the five bow-tie analyses with control reference and evidence record

Barrier ID	**Threat addressed**	**Barrier function and proposed performance standard**	**Control reference and proposed owner**	**Verification evidence**
BT1-P1	Truck leaves the approved route or enters a HEMM-only area	Trip pass with approved route; no unauthorised deviation Performance check: Route and road controls are serviceable; restrict movement if they are not.	5.3 step 7; 5.4 Owner: Gate or dispatch official	Entry and authorisation register

BT1-P2	Unbriefed or unfit driver	Induction/briefing and fitness declaration before entry Performance check: verify control before task; suspend work if it fails.	5.3 steps 3, 6 Owner: Mine manager or authorised official	Driver induction and briefing record
BT1-P3	Brake, steering, light or mirror defect	Pre-entry critical check; reject and hold a defective truck Performance check: verify control before task; suspend work if it fails.	5.3 steps 4, 5; Table 5 Owner: Mine manager or authorised official	Pre-entry vehicle check
BT1-P4	Dust, darkness, rain or fog reduce visibility	Visibility trigger: slow down or stop at holding area; lighting, dust control Performance check: route and road controls serviceable; restrict movement if not.	5.4; 5.10 Owner: Traffic marshal	Traffic / route inspection
BT1-P5	Mixed traffic at junctions and crossings	Route separation, one-way flow, HEMM priority, marshal at crossings Performance check: route and road controls serviceable; restrict movement if not.	5.4; 5.1, Table 3 Owner: Gate or dispatch official	Traffic / route inspection
BT1-M1	Recovery after the top event	Site speed limit and safe following gap reduce impact energy Performance check: Verify control before the task; suspend work if it fails.	5.4 Owner: Mine manager or authorised official	Traffic / route inspection
BT1-M2	Recovery after the top event	Seat belt worn; cabin, mirrors and camera in working order	5.4; Table 5 Owner: Mine manager or	Pre-entry vehicle check

		Performance check: pass entry check; hold and recheck any failure.	authorised official	
BT1-M3	Recovery after the top event	Stop, raise alarm, first aid and emergency response; scene preserved Performance check: pass entry check; hold and recheck any failure.	5.9 Owner: Mine manager or authorised official	Incident / near-miss report
BT2-P1	Brake, steering or tyre failure	Pre-entry check of brakes, steering and tyres Performance check: Pass the entry check, hold, and recheck any failure.	5.3 steps 4, 5; Table 5 Owner: Gate or dispatch official	Pre-entry vehicle check
BT2-P2	Overspeed, fatigue or impairment	Fitness declaration; speed limits from approved transport rules Performance check: Verify control before the task; suspend work if it fails.	5.3 step 3; 5.4 Owner: Gate or dispatch official	Entry and authorisation register
BT2-P3	Weak edge, missing berm, poor drainage or steep grade	Haul-road, edge and drainage inspection and maintenance Performance check: route and road controls serviceable; restrict movement if not.	5.4; Table 4, task 4 Owner: Road or traffic supervisor	Traffic / route inspection
BT2-P4	Overload or uneven load raises the centre of gravity	Payload check, even loading, weighbridge on every dispatch Performance check: Authorised and secure loads were confirmed before release.	5.5 step 5; 5.8 step 2 Owner: Loading or weighbridge supervisor	Loading and weighbridge record
BT2-P5	Wet or slippery road after rain	Restrict or suspend movement after rain or road damage	5.4; 5.9; 5.10	Traffic / route inspection

		Performance check: route and road controls serviceable; restrict movement if not.	Owner: Road or traffic supervisor	
BT2-M1	Recovery after the top event	Edge berm and approved route keep a drifting truck on the road Performance check: Route and road controls are serviceable; restrict movement if they are not.	5.4 Owner: Road or traffic supervisor	Traffic / route inspection
BT2-M2	Recovery after the top event	Seat belt and intact cabin protect the occupant Performance check: pass entry check; hold and recheck any failure.	5.4; Table 5 Owner: Gate or dispatch official	Pre-entry vehicle check
BT2-M3	Recovery after the top event	Emergency stop, alarm, rescue and first aid Performance check: pass entry check; hold and recheck any failure.	5.9 Owner: Gate or dispatch official	Incident / near-miss report
BT3-P1	Reversing without a banksman or in a blind area	Layout avoids reversing; designated zone with trained banksman Performance check: The process was stopped if an agreed signal or contact was lost.	5.6 Owner: Traffic marshal or banksman	Traffic / route inspection
BT3-P2	Reversing alarm, camera or mirror defective	Alarm, camera and mirrors checked before entry Performance check: pass entry check; hold and recheck any failure.	5.3 step 4; Table 5 Owner: Gate inspector	Pre-entry vehicle check
BT3-P3	Driver or helper outside the cab	Driver stays in cab or protected waiting place; no standing between vehicles	5.5 steps 1, 3	Loading and weighbridge record

	near moving trucks	Performance check: verify control before task; suspend work if it fails.	Owner: Gate inspector	
BT3-P4	Queue too close; trucks crowd the loading zone	Holding area, marked spacing, marshal-controlled entry Performance check: verify control before task; suspend work if it fails.	5.5 steps 1, 2 Owner: Traffic marshal or banksman	Traffic / route inspection
BT3-P5	Loader swing zone; truck and loader miscommunicatio n	Agreed signals; exclusion zone; loader waits for correct position Performance check: stop if agreed signal or contact is lost.	5.5 steps 2, 4 Owner: Loading supervisor	Loading and weighbridge record
BT3-M1	Recovery after the top event	Truck stops at once if banksman is lost from view or signal is unclear Performance check: stop if agreed signal or contact is lost.	5.6; 5.10 Owner: Traffic marshal or banksman	Incident / near-miss report
BT3-M2	Recovery after the top event	Marshal stops traffic and clears the area Performance check: verify control before task; suspend work if it fails.	5.1, Table 3; 5.5 Owner: Traffic marshal or banksman	Traffic / route inspection
BT3-M3	Recovery after the top event	First aid, emergency call and casualty care Performance check: Response resources and roles available in the site plan.	5.9 Owner: Gate inspector	Incident / near-miss report
BT4-P1	Worker climbs onto the body,	Ground-level or mechanised cover system; climbing prohibited	5.7 step 2	Tarpaulin covering record

	wheel or load to spread the cover	Performance check: cover secured from ground level; no climbing.	Owner: Loading supervisor or tarpaulin-bay supervisor	
BT4-P2	Covering done at the loading point or on a live route	Designated level tarpaulin bay away from through traffic and loader swing zone Performance check: cover secured from ground level; no climbing.	5.7 step 1 Owner: Loading supervisor or tarpaulin-bay supervisor	Tarpaulin covering record
BT4-P3	Truck moves or is started while workers are at the body	Truck stationary: parking brake on, ignition controlled, persons clear of its path Performance check: cover secured from ground level; no climbing.	5.7 step 3 Owner: Loading supervisor or tarpaulin-bay supervisor	Tarpaulin covering record
BT4-P4	Wet, dusty, dark or windy conditions; unstable load surface	Defer covering in rain, wind, darkness or poor visibility; bay lighting Performance check: cover secured from ground level; no climbing.	5.7 step 5; 5.10 Owner: Loading supervisor or tarpaulin-bay supervisor	Tarpaulin covering record
BT4-P5	Loose cover re-secured on the haul road or at the exit	Stop only at bay or nearest safe place; no roadside re-securing Performance check: cover secured from ground level; no climbing.	5.8 step 3; 5.7 step 7 Owner: Loading supervisor or tarpaulin-bay supervisor	Loading and weighbridge record
BT4-M1	Recovery after the top event	If elevated access is unavoidable: assessed platform, guardrail or fall arrest, trained worker	5.7 step 4 Owner: Loading supervisor or	Tarpaulin covering record

		Performance check: cover secured from ground level; no climbing.	tarpaulin-bay supervisor	
BT4-M2	Recovery after the top event	Supervisor or spotter keeps people clear of traffic and can stop work Performance check: cover secured from ground level; no climbing.	5.7 step 5; 5.10 Owner: Loading supervisor or tarpaulin-bay supervisor	Tarpaulin covering record
BT4-M3	Recovery after the top event	Cover checked from the ground; lights, mirrors and view not obstructed Performance check: cover secured from ground level; no climbing.	5.8 step 3; 5.7 step 6 Owner: Loading supervisor or tarpaulin-bay supervisor	Loading and weighbridge record
BT4-M4	Recovery after the top event	First aid, emergency call and casualty handling; restart check Performance check: cover secured from ground level; no climbing.	5.9; 5.10 Owner: Loading supervisor or tarpaulin-bay supervisor	Incident / near-miss report
BT5-P1	Loading by eye above the rated payload	Payload and tare confirmed at gate; load within permitted payload Performance check: authorised payload and secure load confirmed before release.	5.3 step 2; 5.5 step 5 Owner: Loading or weighbridge supervisor	Loading and weighbridge record
BT5-P2	Uneven or peaked load; material above the sides	Even loading; nothing above the sides; supervisor release check Performance check: authorised payload and secure load confirmed before release.	5.5 steps 5, 6 Owner: Loading or weighbridge supervisor	Loading and weighbridge record

BT5-P3	Weighbridge bypassed, misread or not working	Weigh every dispatch; hold, correct and reweigh Performance check: authorised payload and secure load confirmed before release.	5.8 step 2 Owner: Loading or weighbridge supervisor	Loading and weighbridge record
BT5-P4	Tailgate, latch or cover not secured	Tailgate and tarpaulin verified before release and at exit Performance check: authorised payload and secure load confirmed before release.	5.5 step 6; 5.8 step 3; 5.7 Owner: Loading or weighbridge supervisor	Tarpaulin covering record
BT5-P5	Pressure to dispatch quickly	Any person may stop work; overloaded truck is not released Performance check: authorised payload and secure load confirmed before release.	5.1, Table 3; 5.10 Owner: Loading or weighbridge supervisor	Audit and corrective-action log
BT5-M1	Recovery after the top event	Excess removed at designated correction area, then reweighed Performance check: authorised payload and secure load confirmed before release.	5.8 step 2 Owner: Loading or weighbridge supervisor	Loading and weighbridge record
BT5-M2	Recovery after the top event	Speed and route restriction until the load is verified Performance check: authorised payload and secure load confirmed before release.	5.4 Owner: Loading or weighbridge supervisor	Traffic / route inspection
BT5-M3	Recovery after the top event	Spill cleared; incident reported; corrective action closed	5.9; 5.12 Owner: Loading or	Audit and corrective-action log

		Performance check: Response resources and roles available in the site plan.	weighbridge supervisor	

6. Discussion

6.1. Comparison with the Literature

The framework is consistent with the attention earlier studies have given to vehicles, roads, and human factors in mining-truck accidents. Fault tree analysis of haul-truck fatal accidents (Zhang et al. 2014), injury-severity analysis of earthmoving equipment accidents (Kazan and Usmen 2018), and analysis of off-road truck accidents (Dindarloo et al. 2016) address factors that the pre-entry check, route controls, and briefing proposed here are intended to control (Sections 5.3 and 5.4). Studies on haul road design and dump-point berms emphasise that road geometry and edge protection affect the outcome of a loss of control (Thompson et al. 1998; Giacomini and Thoeni 2015), which is the basis of the road-edge barriers in BT2. The Indian haul road notification sets out the corresponding requirements (Section 3) (Ministry of Labour and Employment, 2018a).

The risks of reversing and blind areas are well documented. Evaluations and reviews of proximity warning and collision avoidance technologies have described both their potential and limitations (Ruff 2007; Teizer et al. 2010; Hrica et al. 2022), and the design of the reversing area and the role of a banksman remain important. This is why the framework prioritises a layout that avoids reversing and treats technology as an additional barrier (Section 5.6). Overloading is associated with greater injury severity in truck crashes (Wen et al. 2022), and studies of drivers' accidents during loading and unloading describe hazard scenarios on and around the truck (Shibuya et al. 2010); both support the payload, weighbridge, and loading controls in Sections 5.5 and 5.8.

The verification approach follows recent studies on critical controls and process safety indicators (Hopkins 2009; Reiman and Pietikäinen 2012; Catala et al. 2024; Mello et al. 2025). Its distinctive features are the treatment of the visiting truck as a managed entity with authorisation, briefing, and record trail, and the treatment of tarpaulin covering as a task with its own bay, record, and bowtie (BT4). The sources cited in this study do not examine consumer trucks as a separate category; therefore, the framework should be read as an extension of the published findings on mining trucks to a vehicle group that has received less attention.

6.2. Application at a Mine

Implementation should follow a hierarchy to ensure that administrative records do not substitute physical risk reduction. First, establish minimum entry conditions: authorised trip and route,

understood briefing, fit driver, and acceptable safety-critical vehicle condition. Next, prioritise engineering and layout controls: separate traffic, remove reversing, provide a safe loading layout, and designate a tarpaulin bay or mechanised covering arrangement. Administrative controls, including briefings, marshals, dispatch controls, and stop-work authority should be assigned. Finally, assurance checks, indicator reviews, and corrective action tracking were introduced. A mine may phase implementation according to risk and resources, but should not release a movement where minimum control is absent. Paper or electronic records can be integrated into a dispatch system using a unique movement identifier; each record must still identify its control, verifier, and outcome.

- The mine transport rules and route maps are attached to these arrangements.
- List the approved routes, one-way sections, crossings with heavy earth-moving machinery, loading points, holding locations, weighbridges, and exits.
- Enter site-assessed speed limits, following distances, reversing zone boundaries, weather and visibility triggers and communication channels.
- Identify the vehicle types that visit the mine and the applicability of each statutory and gazette requirement (DGMS, 2017; Ministry of Labour and Employment, 2018a; Ministry of Labour and Employment, 2018b).
- Name the role authorised to close routes, suspend entries, and restart operations after a stop-work event.
- Risk assessment should be completed in consultation with drivers, dispatchers, security staff, loading staff, contractors and safety officials.
- Identify the tarpaulin bay and cover system, and name the supervisor responsible.

6.3. Limitations and Future Research

The framework is conceptual and has not undergone stakeholder validation, site walkthroughs, pilot implementation, or field testing. The documentary search was targeted and non-systematic; its database coverage, query history, screening counts, and selection decisions were not recorded in a manner that permits replication; therefore, relevant sources may have been missed. The hazard list, ratings, and barrier selection reflect the authors' judgment and have not been independently reviewed; no inter-rater agreement or sensitivity analysis was calculated. The ratings do not estimate the accident frequency, effect size, implementation fidelity, or comparative effectiveness. Indian incident summaries do not consistently classify vehicles as consumer trucks, preventing the estimation of their share of accidents. Some evidence of hazards comes from non-mining road transport or other jurisdictions. The cited regulations and notifications concern coal mines; their applicability to a specific visiting vehicle depends on its legal classification, design, use, and the wording of the relevant provision, and their applicability to other mining sectors requires a separate review.

Future evaluations should begin with a structured review by drivers, dispatchers, security personnel, loading staff, contractors, mine managers, and safety professionals. Subsequent pilot studies should record implementation fidelity, control failures, exposure denominators, and event outcomes; test inter-rater agreement and sensitivity of the ratings; and compare the framework with existing site traffic management arrangements. Incident reporting should identify the vehicle category and task stages. These steps are necessary before any claims regarding effectiveness or risk reduction can be made in the future.

7. Recommendations

Based on this framework, the following actions are recommended for mine management:

- Transport rules and operating procedures for each vehicle category, including consumer trucks must be established.
- Map the routes, separate consumer trucks from heavy earth-moving machinery where possible, and control the remaining crossings.
- Plan loading and holding areas to avoid reversing, and use a trained banksman where it cannot be avoided.
- Vehicles should be inspected before entry, and defective vehicles should be held until they are repaired and re-inspected.
- Provide a tarpaulin bay or mechanised cover system so that no one can climb onto the load.
- Link loading, payload, and dispatch records to ensure that every dispatch is weighed and that every overload is corrected.
- Review route deviations and near-misses at safety meetings using the indicators listed in Table 7.
- Reassess the risks after an incident or changes in route, equipment, or conditions.

8. Conclusions

This study proposes a site-adaptable framework for consumer trucks in Indian opencast coal mines. It organises movement into six stages and connects an eleven-task hazard register, ten proposed indicators, and five bow-tie analyses with control owners and verification evidence. It also treats tarpaulin covering as a distinct task and sets out stop work and restart arrangements. These are design outputs from a targeted documentary synthesis and are not validated.

The framework's contribution is the operational integration of established traffic and contractor-management principles for externally controlled short-stay trucks, including covering and movement from gate to exit. The risk ratings are hypothetical judgments, the legal applicability of individual provisions remains vehicle- and site-specific, and the proposed controls have not been validated or field-tested. Therefore, the framework cannot establish accident reduction or comparative effectiveness. However, stakeholder reviews, site-specific legal assessments, and phased field evaluations using exposure-based data are required before it can be considered an effective intervention.

Declarations

Acknowledgements and Disclaimer

The author's name and professional affiliation are provided for identification purposes only. The views, analysis, and conclusions expressed in this paper are those of the author in a personal scholarly capacity and do not necessarily represent the official views, policies, or position of the Directorate General of Mines Safety, the Government of India, or any mine management. The proposed framework is conceptual and is not an official DGMS guideline, direction, or

interpretation. Its application should be assessed against current legal requirements and site-specific conditions.

Author Contributions

N.B. conceptualised the study, conducted the literature review, and prepared and revised the manuscript. The author has read and agreed to the published version of the manuscript.

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No new datasets were generated; the framework was based on published and publicly available data.

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Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the author used generative AI tools to assist with literature searching, drafting, language editing, and preparing the code used to create the figures. The author reviewed and edited all content and checked every cited reference against its publisher record (DOI) and took full responsibility for the content of the publication.

Conflicts of Interest

The authors declare no conflict of interest.

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