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Improving Accuracy of Production Volume Reconciliation and Reducing Dumping Rollover Safety Risk Through Vessel Modification Using UHMWPE Lining on Dump Truck Mercy 2528 in Basalt Mining Hauling Operations

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ABSTRACT

Abstract: Carry back — residual soil and clay material adhering to the vessel of dump trucks after dumping — has long been treated as a minor operational nuisance in basalt mining hauling operations. In practice, however, it carries a dual consequence: it directly distorts production accounting, because the volume recorded by Joint Survey (topographic reconciliation) diverges from the volume recorded by Truck Count, and it creates an uneven, off-balance vessel load during the dumping maneuver, a condition independently documented by mine safety regulators as a contributing cause of haul truck tip-over and rollover incidents. At the basalt mining project of PT Putra Perkasa Abadi, Site PT Maruwai Coal, baseline data from January–February 2026 recorded a Joint Survey vs Truck Count achievement of only 76–77%, equivalent to an average monthly revenue loss of approximately Rp370,019,109, alongside an internally assessed dumping-rollover risk rating of S15 on the site risk matrix. A Pareto analysis of the January–April 2026 deviation confirmed that the two earliest months alone accounted for 75.9% of the cumulative loss, while root cause analysis using a cause-and-effect (fishbone) diagram identified the dominant factor as the existing mild-steel vessel plate of Dump Truck Mercy 2528, which is unsuitable for hauling high-moisture soil and clay due to its high coefficient of friction. Contributing but non-dominant factors were inconsistent operator loading practice and the absence of a weekly Joint Survey monitoring system. A structured Quality Control Circle (QCC) intervention was implemented from March to June 2026, consisting of (1) lining the vessel with Ultra High Molecular Weight Polyethylene (UHMWPE) plates, a material with a very low coefficient of friction that prevents wet material from adhering to the surface, (2) in-class operator training on loading consistency, and (3) a new weekly Joint Survey monitoring standard operating procedure. Following the intervention, the Joint Survey vs Truck Count achievement increased progressively to 94–95% in March–April and reached 100% in June 2026, the dumping-rollover risk rating was reduced from S15 to L3, and no loss-time injury related to vessel dumping was recorded during the evaluation period. The projected annual gain in reconciled revenue was estimated at Rp4,137,829,310.88 against an annualized improvement cost of Rp302,400,000 for two plate replacement cycles. These results indicate that a low-cost material engineering intervention, when combined with human-factor training and a systemic monitoring safeguard, can simultaneously improve production volume reconciliation accuracy and substantially reduce the safety risk associated with unbalanced vessel loads during dumping.

Keywords: *Carry back, UHMWPE vessel lining, dump truck, joint survey reconciliation, dumping rollover safety, risk matrix, basalt mining*

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Introduction:

Background

Accurate production volume reconciliation is a fundamental requirement of good mining practice. In open-pit mining operations, the volume of overburden or ore actually moved is typically verified through two independent measurements: Joint Survey, a topographic reconciliation between the contractor and the customer, and Truck Count, an operational estimate derived from the number of hauling cycles multiplied by the rated vessel capacity of each dump truck. When these two figures diverge beyond an acceptable tolerance, the discrepancy directly affects revenue recognition, KPI achievement, and the credibility of production reporting to the customer.

One recurring but frequently underestimated cause of this divergence is carry back — material that remains adhered to the vessel after the dumping cycle instead of discharging completely. Because carry back is transported back to the loading front and mixed with the next load, it is rarely visible in routine operational reporting, yet its cumulative effect on reconciliation accuracy can be substantial. Industry studies of underground haul trucks have documented carry back in the majority of hauling cycles, with measurable tonnage losses translating into significant annual revenue impact (Knights & Reuter, 2023).

At the basalt mining project operated by PT Putra Perkasa Abadi at Site PT Maruwai Coal (MAC), this issue became evident on Dump Truck Mercy 2528, a unit assigned to haul overburden and soil from Pit Basalt to the disposal area. Field observation showed that soil and clay material with high moisture content frequently adhered to the vessel wall after dumping, being carried back to the loading front instead of being fully discharged. Baseline data for January–February 2026 recorded a Joint Survey vs Truck Count achievement of only 76–77%, corresponding to an average monthly loss of approximately Rp370,019,109.

This condition indicates that the technical suitability of vessel material for the characteristics of the material being hauled is as critical to production accuracy as the measurement methodology itself. Where the vessel surface is not compatible with the physical properties of the transported material, the resulting carry back does not merely reduce productivity; it systematically biases the reconciliation between survey-based and count-based production data.

Beyond its effect on production accounting, carry back also carries a direct safety consequence. When residual material adheres unevenly to one side or corner of the vessel rather than discharging completely, the load remaining in the tray becomes asymmetric at the moment the vessel is raised to its maximum dumping angle — precisely when the truck's centre of gravity is highest and its lateral stability is lowest. Internal risk assessment at the basalt mining project rated this condition, referred to locally as “DT rebah” (dump truck tipping during unloading), at a risk level of S15 on the site risk matrix prior to intervention, and it was identified by the Departemen SHE (Safety, Health, and Environment) as a contributing factor to loss-time injury (LTI) exposure. This safety dimension is treated in this study as a co-equal outcome alongside production volume reconciliation, rather than as a secondary consequence.

In response, PT Putra Perkasa Abadi initiated a structured improvement project using the Quality Control Circle (QCC) methodology, integrating a material engineering intervention — lining the vessel with Ultra High Molecular Weight Polyethylene (UHMWPE) — with complementary improvements in operator practice and monitoring systems. This study documents the identification, intervention, and evaluation of that improvement project.

Literature Review

Carry back has been increasingly recognized in the mining engineering literature as a measurable, economically significant source of production loss rather than a purely cosmetic operational issue. A seven-month analysis of load-volume-scanner data from an underground gold mine in Central Queensland found carry back present in 62% of all hauling cycles, with a mean carry back of approximately 0.4 tonnes per cycle; the cumulative loss over the study period was valued at roughly AUD 370,000, in addition to distorting the reconciliation between mined and milled tonnage by around 0.54% (Knights & Reuter, 2023). This finding is consistent with observations at the basalt mining project, where deviation between Joint Survey and Truck Count was concentrated in the months with the highest incidence of vessel carry back.

Technological approaches to reducing measurement error from carry back have generally focused on detection rather than prevention. Payload monitoring systems installed on modern haul trucks re-establish the empty vessel weight after every dumping cycle specifically to prevent carry back from being erroneously counted as part of the next payload, while image-recognition-based volume detection systems have been proposed as a lower-cost alternative to sensor-based payload monitoring, particularly in open-pit operations where weighbridge coverage is limited (Sun et al., 2021). These approaches confirm that carry back is a widely acknowledged confound in production measurement, but they primarily manage its consequences rather than eliminating its physical cause at the vessel surface.

The physical cause of carry back is closely related to the frictional interaction between the transported material and the vessel surface. Wet cohesive materials such as clay and fine soil tend to adhere strongly to standard mild-steel vessel plates, particularly as the plate surface roughens and oxidizes with continued use. Ultra High Molecular Weight Polyethylene (UHMWPE) has been widely adopted in bulk material handling as a liner material precisely because of its very low coefficient of friction against sliding counterfaces; tribological testing has recorded UHMWPE-on-steel friction coefficients as low as 0.09–0.14, considerably lower than uncoated steel surfaces (Wang & Li, 1999). This property is the basis for its established use in transfer chutes, hoppers, and dump truck vessel liners as a means of preventing material adhesion and ensuring complete discharge during dumping.

Beyond the technical and material aspects, mining safety regulation in Indonesia — including the Decree of the Minister of Energy and Mineral Resources No. 1827 K/30/MEM/2018 concerning the guidelines for implementation of Good Mining Practice — requires that mining equipment and its operational condition be properly maintained and monitored to avoid conditions that could compromise operational safety, including imbalanced vessel loads that increase the risk of a dump truck tipping during unloading (ESDM, 2018).

The safety significance of an unbalanced or incompletely discharged vessel load is independently supported by mine safety incident data. The U.S. Mine Safety and Health Administration recorded 14 injury accidents involving over-the-road haul trucks and 28 injury accidents involving off-road mine haul trucks that tipped or rolled over while dumping between 2018 and 2024, and identified uneven ground, unbalanced load, and elevated centre of gravity during the raised-bed dumping maneuver as recurring contributing factors (MSHA, 2024). Because carry back by definition leaves residual material unevenly distributed within the vessel at the point of maximum tray elevation, it is directly consistent with the load-imbalance mechanism identified in these incident records, reinforcing the rationale for treating carry back as a safety hazard and not solely a measurement error.

Research Gap

Although the economic impact of carry back and the availability of detection technologies have both been documented, several gaps remain in the existing literature relevant to this study:

1. Most published studies on carry back focus on detection and quantification (load volume scanners, image recognition, onboard payload systems) rather than on eliminating its physical cause through vessel material modification.
2. There is limited literature examining the specific interaction between locally variable overburden material characteristics — such as basalt-associated soil and clay with high moisture content — and vessel liner material selection in a working mine setting.
3. Few studies quantitatively link a vessel material intervention to both production reconciliation accuracy (Joint Survey vs Truck Count achievement) and financial outcomes at the level of an individual operating unit.
4. Carry back and dumping-related rollover risk are typically studied in separate literatures — production reconciliation studies rarely quantify the associated safety risk, while haul truck rollover safety studies rarely trace the mechanism back to a correctable material root cause such as vessel liner selection.
5. There is limited documentation of how a low-cost material intervention can be combined with human-factor training and a systemic monitoring safeguard within a structured continuous-improvement framework such as Quality Control Circle (QCC).

This study addresses these gaps by evaluating a combined intervention — UHMWPE vessel lining, operator training, and a new weekly monitoring SOP — using field production and financial data from an operating basalt mining site.

Novelty and Rationale of the Study

1. This study focuses on a specific, field-verified root cause of production reconciliation error — vessel material incompatibility with high-moisture soil and clay — rather than treating carry back solely as a measurement problem to be corrected downstream.
2. It adopts an integrative approach that combines: (a) a material engineering intervention (UHMWPE vessel lining), (b) enhancement of operator loading consistency through training, and (c) a new weekly Joint Survey monitoring SOP to prevent recurrence.
3. The effectiveness of the intervention is evaluated using quantitative indicators, including: Joint Survey vs Truck Count achievement (%), monthly loss/gain revenue, a Pareto-based prioritization of deviation contribution by month, and the site's dumping-rollover risk matrix rating before and after intervention.
4. Production reconciliation accuracy and dumping-rollover safety risk are evaluated jointly, on the premise that both outcomes share the same physical root cause — incomplete and uneven vessel discharge — and should therefore respond concurrently to the same material intervention.

The rationale of this study is based on the magnitude of revenue loss attributable to carry back at the basalt mining project (an average of Rp370,019,109 per month during the baseline period) and the absence of a standing mechanism to detect and correct such deviations before they accumulate. A measurable, low-cost, and field-validated intervention is therefore both operationally and financially justified.

Research Objectives

The objectives of this study are:

1. To analyze the contribution of vessel carry back to the deviation between Joint Survey and Truck Count on Dump Truck Mercy 2528.
2. To identify the dominant root cause of carry back through cause-and-effect and root cause verification analysis.
3. To evaluate the effectiveness of UHMWPE vessel lining, combined with operator training and a weekly monitoring SOP, in improving Joint Survey vs Truck Count achievement.
4. To quantify the financial impact of the intervention, including investment cost and projected annual gain in reconciled revenue.
5. To assess the associated safety benefit of eliminating unbalanced vessel loads during the dumping cycle, including the change in the site's dumping-rollover risk matrix rating and loss-time injury (LTI) exposure before and after intervention.

Methods:

Study Design

This study employs a quantitative approach using a quasi-experimental design (before–after study), comparing Joint Survey vs Truck Count reconciliation performance and associated financial outcomes before and after the implementation of a vessel modification intervention on Dump Truck Mercy 2528. The quantitative approach was selected because it provides an objective, measurable representation of the change in reconciliation accuracy through concrete indicators, namely monthly achievement percentage and loss/gain revenue in Rupiah.

The quasi-experimental design was applied because the study does not involve a randomized control group; rather, it observes a single operating unit (and its associated fleet) under two time conditions — the pre-intervention baseline (January–February 2026) and the post-intervention period (May–June 2026), with March–April 2026 treated as a progressive implementation phase. Randomization was not practical in this operational context, as the mining hauling cycle must continue uninterrupted and cannot be split into treatment and control fleets without disrupting production commitments to the customer.

The intervention implemented in this study consists of three complementary components: (1) a material engineering improvement in the form of Ultra High Molecular Weight Polyethylene (UHMWPE) plate lining applied to the interior of the vessel, using a bolted installation method to allow future replacement; (2) enhancement of operator competency through in-class training and socialization regarding the relationship between consistent loading practice and Joint Survey vs Truck Count accuracy; and (3) the introduction of a new weekly Joint Survey monitoring standard operating procedure (SOP), assigning a designated Person In Charge (PIC) — the Group Leader of Engineering/Survey — to review deviation on a weekly rather than end-of-month basis, with an escalation threshold of 3%.

Research Location and Timeline

The research was conducted at:

1. Location: Pit Basalt – Disposal hauling road, Basalt Mining Project, PT Putra Perkasa Abadi, Site PT Maruwai Coal (MAC), Central Kalimantan, Indonesia.
2. Study Period: Baseline data – January–February 2026; Root cause analysis and solution planning – February–March 2026; Implementation – March–April 2026; Evaluation – May–June 2026.

Population and Sampling Technique

1. Population: All Dump Truck OB units (3 units) assigned to the Pit Basalt–Disposal hauling route, including Dump Truck Mercy 2528, together with the survey, production, and plant personnel involved in production data recording and vessel maintenance.
2. Sampling Technique: Purposive sampling was applied to the unit exhibiting the most consistent carry back symptoms (Dump Truck Mercy 2528, unit DA55) as the primary intervention object, supported by periodic sampling of dump truck vessel capacity across the fleet to verify carry back incidence prior to and following the intervention.

Data Collection Procedures and Instruments

Secondary Data:

a. Monthly Joint Survey and Truck Count reconciliation records (January–June 2026)
b. Financial verification records (rate per Bcm, monthly loss/gain revenue)
c. Vessel technical specification and material data sheet
d. Site risk matrix assessment for the dumping-rollover hazard ("DT rebah"), before and after intervention, and Departemen SHE incident/LTI records for the evaluation period

Primary Data:

a. Field observation and photographic documentation of vessel condition before and after dumping
b. Dump Truck Capacity sampling forms, recording joint survey volume per ritase
c. Cause-and-effect (fishbone) analysis conducted with the engineering and production team

Research Instruments:

a. Sampling Dump Truck Capacity form (PT PPA Site MAC)
b. Cause-and-effect diagram and root cause verification matrix
c. SOP Monitoring Joint Survey Mingguan (Weekly Joint Survey Monitoring SOP), No. PPA-MAC-SOP-ENG-015
d. Site dumping-rollover risk matrix (Severity–Likelihood rating scale, e.g. S15, L3), maintained by Departemen SHE

Statistical Analysis

Baseline data were first mapped using a Pareto analysis of monthly deviation between Joint Survey and Truck Count for January–April 2026, in order to identify which period contributed most significantly to the cumulative production loss and thereby justify the urgency of intervention (see Results, Figure 1).

As shown in the results, the deviation was concentrated in the earliest months of the observation period, before the vessel modification was implemented, and diminished progressively as the intervention was rolled out — consistent with the expected effect of a material-based root cause being progressively corrected.

Root cause analysis was subsequently performed using a cause-and-effect (fishbone) diagram structured around three categories: Material, Man, and Method. Under Material, the dominant contributing factor identified was that the existing vessel plate (mild steel) was not compatible with hauling soil and clay of high moisture content, owing to its relatively high coefficient of friction upon contact with wet material. Under Man, inconsistency in operator loading practice was identified, linked to limited operator understanding of how loading consistency affects Joint Survey vs Truck Count accuracy. Under Method,

the absence of a weekly Joint Survey monitoring mechanism was identified, with monitoring previously limited to end-of-month reconciliation.

A root cause verification matrix was then used to determine which of the three candidate causes was dominant. The Material-related cause was verified as dominant because it directly and physically produced the carry back symptom observed in the field (vessel not fully discharging after dumping), whereas the Man- and Method-related causes were verified as contributing but non-dominant, since they affected the speed of detection and consistency of loading rather than causing the physical adhesion of material to the vessel itself.

In parallel with the production reconciliation analysis, the dumping-rollover risk associated with carry back was evaluated descriptively by comparing the Departemen SHE risk matrix rating recorded before intervention with the rating recorded after the vessel modification, operator training, and monitoring SOP had been fully implemented, alongside a review of LTI records for the evaluation period.

Scope and/or Limitations of the Methodology Used

The scope of this study is limited to the technical intervention applied to Dump Truck Mercy 2528 and its associated fleet on the Pit Basalt–Disposal hauling route, evaluated through Joint Survey vs Truck Count reconciliation and financial verification indicators.

This study has several methodological limitations. First, it does not statistically isolate the individual contribution of each of the three intervention components (vessel lining, operator training, and weekly monitoring SOP) to the overall improvement in achievement; the reported result reflects their combined effect. Second, external factors such as extreme rainfall, which may independently affect material moisture content and therefore carry back severity, were not separately modeled. Third, the financial projection for the 12-month gain in revenue assumes that the achievement level observed in May–June 2026 is sustained for the remainder of the year, an assumption that depends on continued vessel plate maintenance and monitoring SOP compliance.

Results

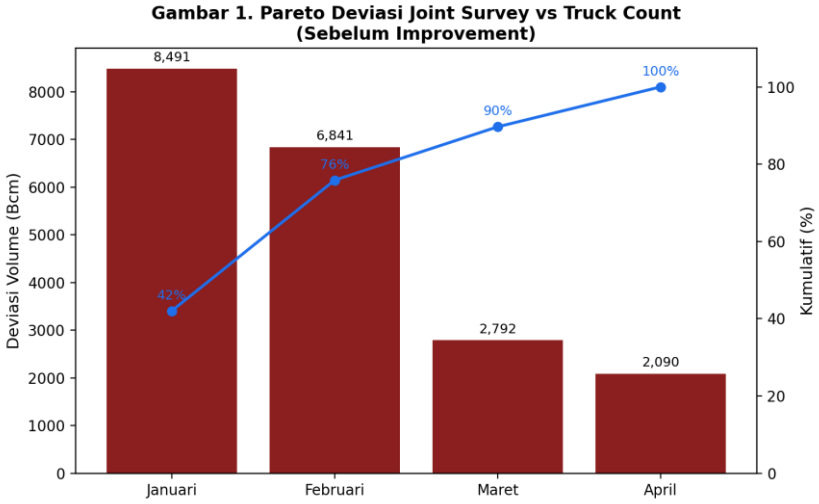


Figure 1. Pareto Analysis of Monthly Deviation Between Joint Survey and Truck Count, January–April 2026 (Before Improvement)

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As shown in Figure 1, the deviation between Joint Survey and Truck Count for January–April 2026 was heavily concentrated in the first two months of observation. January and February 2026 together accounted for 75.9% of the cumulative deviation volume (20,213 Bcm) recorded over the four-month baseline and progressive-implementation period, consistent with the Pareto principle. This finding confirmed that the carry back issue on Dump Truck Mercy 2528 was both significant and time-critical, providing the quantitative justification for prioritizing the vessel lining intervention rather than deferring it for further observation.

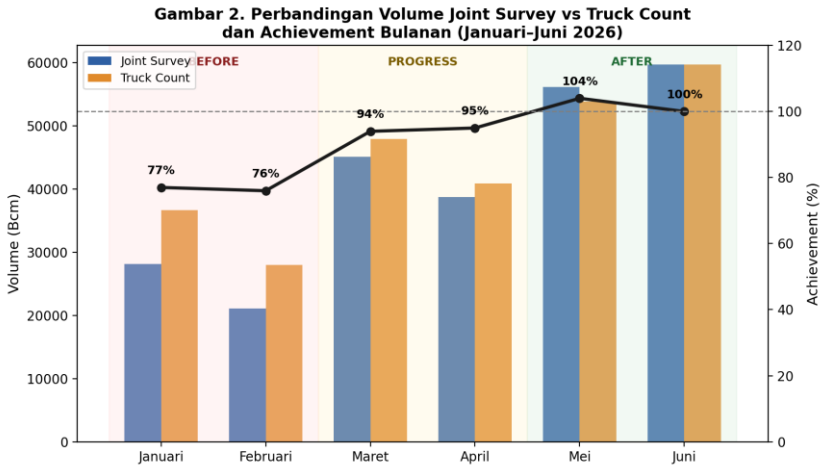


Figure 2. Joint Survey vs Truck Count Volume and Monthly Achievement, January–June 2026

Figure 2 presents the monthly Joint Survey and Truck Count volumes alongside the resulting achievement percentage across the full six-month observation period. During the baseline period (January–February 2026), achievement remained at 76–77%, reflecting substantial carry back loss. Following the start of intervention in March 2026, achievement rose to 94% and 95% in March and April respectively, corresponding to the progressive rollout of vessel lining across the fleet and the initial phase of operator training. By May and June 2026, following full implementation of the UHMWPE lining, operator training, and the weekly monitoring SOP, achievement reached 104% and 100% respectively — indicating that Joint Survey and Truck Count volumes had converged, with carry back effectively eliminated as a source of reconciliation error.

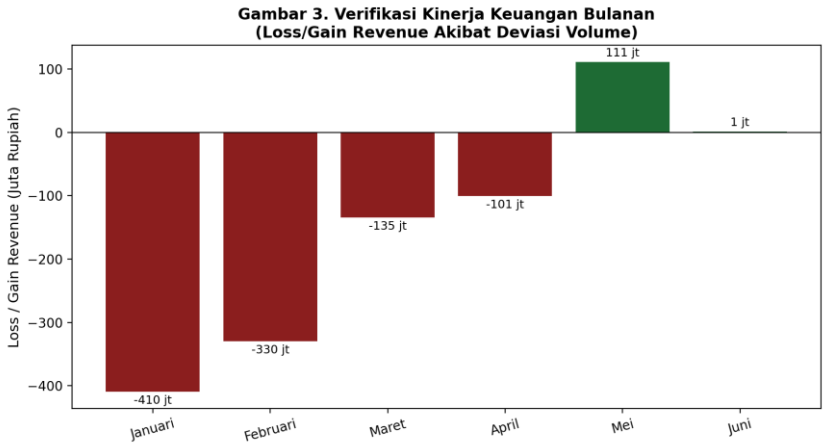


Figure 3. Monthly Loss/Gain Revenue Resulting From Joint Survey vs Truck Count Deviation, January–June 2026

Figure 3 translates the reconciliation deviation into financial terms using the applicable production rate of Rp48,268 per Bcm. The baseline months of January and February 2026 recorded losses of Rp409,824,280.80 and Rp330,213,937.68 respectively, while March and April continued to show reduced but still negative variances of Rp134,742,535.40 and Rp100,869,501.04 as the intervention was progressively rolled out. From May 2026 onward, the sign of the monthly variance reversed to a gain of Rp111,373,583.20, followed by a near-neutral Rp1,399,289.32 in June 2026 as the reconciliation stabilized at 100% achievement.

Based on these results, the loss revenue that would have been incurred over a full 12-month period without any improvement was projected at Rp4,440,229,310.88. Against an annualized improvement cost of Rp302,400,000 — covering two UHMWPE plate replacement cycles per year given an estimated plate service life of six months per cycle, and inclusive of installation labor and consumables — the projected net gain in reconciled revenue for the 12-month period was Rp4,137,829,310.88.

Safety Outcome: Dumping-Rollover Risk Reduction

In addition to the reconciliation and financial outcomes, the intervention was assessed for its safety implication, given that carry back adhering unevenly to one side of the vessel produces an imbalanced load distribution at the point of maximum tray elevation during dumping. Table 1 summarizes the combined production and safety outcome of the intervention.

Indicator	Before Intervention	After Intervention	Change
Dumping-rollover risk matrix rating (“DT rebah”)	S15	L3	↓ Reduced
Joint Survey vs Truck Count achievement	76–77%	100%	↑ +23–24 pp
Loss-time injury (LTI) related to vessel dumping	Risk identified by Dept. SHE	None recorded	↓ Eliminated

Table 1. Combined Production Reconciliation and Safety Outcome, Before vs After Intervention

Prior to the intervention, the Departemen SHE rated the dumping-rollover hazard associated with Dump Truck Mercy 2528 at S15 on the site risk matrix, reflecting the elevated likelihood of an uneven, carry-back-laden vessel becoming unstable during the raised-bed dumping maneuver — a mechanism consistent with the load-imbalance-related tip-over and rollover incidents documented industry-wide (MSHA, 2024). Following the completion of vessel lining, operator training, and the introduction of routine daily P2H (pre-operation) inspection of the UHMWPE plate condition, the same hazard was re-rated at L3, and no loss-time injury related to vessel dumping was recorded on the unit during the May–June 2026 evaluation period. Field reports further confirmed that vessel discharge was complete and evenly distributed after the intervention, and operators reported increased confidence and a reduced sense of risk while dumping — consistent with the stakeholder assessment by Departemen SHE, which identified the intervention as producing a significant reduction in loss-time-injury (LTI) risk associated with DT rebah, alongside improved compliance with company and regulatory safety standards.

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Results and Discussion

Implications

a. Practical Implications: The findings provide a replicable reference for addressing carry back on other dump truck units and fleets operating in overburden material with similarly high moisture content, without requiring investment in dedicated payload-scanning technology, while simultaneously removing a documented rollover hazard mechanism at its physical source.

b. Managerial Implications: The results support data-driven decision-making regarding vessel material specification and maintenance scheduling, and demonstrate that production accuracy and operational safety can be improved together through a single, modestly priced intervention rather than being treated as competing investment priorities.

c. Regulatory and Safety Implications: By reducing the dumping-rollover risk rating from S15 to L3 and eliminating LTI exposure associated with DT rebah during the evaluation period, the intervention supports compliance with mining safety principles under the Decree of the Minister of Energy and Mineral Resources No. 1827 K/30/MEM/2018 concerning the implementation of Good Mining Practice, and directly addresses the load-imbalance mechanism identified in mine haul truck tip-over and rollover incident records (MSHA, 2024).

Research Contribution

a. Proposes a combined intervention model for improving production volume reconciliation accuracy and dumping-rollover safety based on (a) a material engineering solution (UHMWPE vessel lining), (b) a human factor solution (operator training), and (c) a systemic monitoring safeguard (weekly Joint Survey monitoring SOP).

b. Provides field-based, quantified evidence linking a single vessel material root cause to both Joint Survey vs Truck Count reconciliation performance and dumping-rollover risk matrix rating, bridging two literatures — production reconciliation and haul truck rollover safety — that are typically studied separately.

c. Serves as a practical reference for other mining contractors seeking a low-cost, rapidly deployable response to carry back-related production loss.

Limitations

a. This study does not statistically decompose the individual contribution of vessel lining, operator training, and monitoring SOP to the overall improvement, as the three components were implemented concurrently.

b. It does not account for external environmental variables, such as extreme rainfall intensity, that may independently influence material moisture content and carry back severity.

c. The absence of LTI incidents during the two-month post-intervention evaluation window is encouraging but statistically limited; a longer observation period is required before the reduction in dumping-rollover risk can be considered fully validated.

Suggestions

Recommendations for Future Research

a. Incorporate a staggered or sequential rollout design in future studies to statistically isolate the marginal contribution of each intervention component.

b. Extend the evaluation period beyond 12 months to verify the durability of the UHMWPE lining under continuous field conditions and to refine the plate replacement cycle assumption used in this study.

c. Conduct comparative studies across other hauling units and material types (e.g., higher clay content, different pit sources) to assess the generalizability of the intervention.

d. Incorporate quantitative safety indicators, such as a formal risk matrix score for vessel-tipping incidents, alongside reconciliation and financial indicators in future evaluations.

Conclusion

This study analyzed the contribution of vessel carry back to the deviation between Joint Survey and Truck Count, and to dumping-rollover safety risk, on Dump Truck Mercy 2528 in a basalt mining operation. Baseline data for January–February 2026 showed a reconciliation achievement of only 76–77%, equivalent to an average monthly revenue loss of Rp370,019,109, alongside a dumping-rollover risk rating of S15 on the site risk matrix, with a Pareto analysis confirming that the first two months of observation accounted for 75.9% of the cumulative production deviation.

Root cause verification identified the dominant cause as the incompatibility of the existing mild-steel vessel plate with high-moisture soil and clay material, owing to its high coefficient of friction, while inconsistent operator loading practice and the absence of weekly Joint Survey monitoring were verified as contributing but non-dominant factors.

Following the implementation of UHMWPE vessel lining, operator training, and a new weekly Joint Survey monitoring SOP between March and June 2026, the reconciliation achievement increased progressively to 94–95% in March–April and reached 100% in June 2026, while the dumping-rollover risk rating was reduced from S15 to L3 and no loss-time injury related to vessel dumping was recorded during the evaluation period. The projected annual gain in reconciled revenue was Rp4,137,829,310.88 against an annualized improvement cost of Rp302,400,000. These results demonstrate that a single low-cost, field-validated material intervention, when combined with human-factor training and a systemic monitoring safeguard, can simultaneously improve production volume reconciliation accuracy and substantially reduce the safety risk associated with unbalanced vessel loads during dumping — confirming that, in this case, production accuracy and operational safety share a common, correctable root cause.

Acknowledgment

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