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Control of Slippery Conditions on Mining Roads Through Layering with Crusher Reject Material on the Hauling Road from Pit to Rom Pit Basalt PPA During Q4 2025

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ABSTRACT

The slippery condition of the mining road on the Pit to ROM Pit Basalt PPA hauling line is one of the main obstacles to achieving production targets and ensuring work safety. During the January–June 2025 period, the year-to-date slippery value on the Pit to ROM road exceeded the company's standard threshold, reaching an average of 243% or 1.83 hours per rainy event. This high value resulted from limitations in hard materials for road layering, soil conditions prone to slipperiness, suboptimal road geometry, and inadequate drainage systems. The impacts included decreased effective working hours for transportation equipment, increased unsafe conditions, and lost revenue from basalt loading activities. This study aims to evaluate the effectiveness of crusher reject material as an alternative for road layering to control slippery conditions in the Pit to ROM hauling area. It is an applied improvement study, problem-solving oriented, using the Quality Control Project (QCP) approach. The analysis employed quantitative and qualitative methods through before–after comparisons, supported by field observations and technical evaluations of the mining road conditions. The results show that layering with crusher reject material, supported by road geometry improvements and drainage normalization, significantly reduced slippery duration, increased effective working hours for hauler units, and generated revenue gains of Rp460,430,676. This study implies that crusher reject material offers an effective, safe, and economical technical solution for sustainable mining road management.

Keywords: *Mine road, Slippery, Layering, Material reject crusher, Hauling performance*

INTRODUCTION

Mine roads are vital infrastructure in open pit mining activities because they function as the main route for transporting materials from the excavation area (pit) to the processing site or Run of Mine (ROM) (Terziyski, 2024). Good mining road conditions must meet the requirements for safety, stability, and suitability of road geometry such as width and slope (grade) so that hauling activities can run safely, smoothly, and productively (Alawi & Setiaji, 2022; Jiang, 2025; Kolapo et al., 2022). Failure to maintain the quality of the mine roads will have a direct impact on production delays, increased operational costs, and increased risk of work accidents (Yıldız 2021; Joe-Asare et al., 2023).

Globally, poor mining road conditions represent a significant challenge affecting operational efficiency, safety performance, and economic viability across the mining industry (Berberoglu et al., 2024; Chen et al., 2022; Hodge et al., 2022; Milošević et al., 2025). According to the International Council on Mining and Metals (ICMM, 2021), haul road-related incidents account for approximately 35-40% of all mining accidents worldwide, with slippery surface conditions identified as a primary contributing factor, particularly in tropical and subtropical mining regions experiencing high precipitation. Research conducted across multiple mining operations in Australia, South Africa, and South America indicates that inadequate haul road maintenance results in productivity losses ranging from 15% to 25% of total operational capacity, translating to billions of dollars in lost revenue annually (Thompson & Visser, 2006; Czinder et al., 2021). Furthermore, the World Bank (2020) reported that developing countries face disproportionate challenges in maintaining mining road quality due to limited access to high-quality aggregate materials, inadequate drainage infrastructure, and insufficient technical expertise in road engineering.

In Southeast Asian mining operations specifically, studies by Rahim et al. (2019) demonstrated that surface slipperiness during rainy seasons causes average hauling delays of 2.5 hours per precipitation event, significantly impacting production schedules and increasing operational costs through extended equipment idle time, increased fuel consumption, and accelerated vehicle wear. The Mining Industry Safety and Health Centre (2022) emphasized that beyond productivity impacts, poor road conditions substantially elevate accident risks, with wet and slippery surfaces contributing to 42% of haul truck rollovers and loss-of-control incidents globally. These international data underscore that mining road quality management is not merely a localized operational concern but represents a critical global challenge requiring innovative, context-appropriate solutions that balance technical effectiveness, economic feasibility, and environmental sustainability.

In basalt mining activities in the Pit Basalt PPA area, the Pit to ROM road is about 2.8 km long and serves as the main hauling route to the basalt crusher unit. This line should have a stable, non-slippery surface as well as geometry that complies with hauling standards. However, the actual conditions in the field show that the Pit to ROM road has not fully met the criteria for a decent mining road, so it often experiences slippery conditions, especially during and after rain.

The main problem faced on the Pit to ROM route is the unavailability of hard materials (overburden) in the pit area that can be used as layering materials or road pavement. The road surface which is dominated by soil material has the characteristic of easily absorbing water and losing carrying capacity when wet. As a result, every time it rains, the road surface becomes slippery and takes a long time to return to being suitable for hauling units (Sadeghi & Goli, 2024).

WEATHER		Jan-25	Feb-25	Mar-25	Apr-25	May-25	Jun-25
Rain	Plan Rain	92.25	89.67	104.82	109.9	103.55	80.42
	Actual Rain	178.45	145.85	153.60	222.6	228.62	116.48
	ACV	193%	163%	147%	203%	221%	145%
Slippery	Plan Slip	23.25	21.00	23.3	22.5	23.25	22.50
	Actual Slip	57.48	47.17	46.9	72.4	47.22	58.10
	ACV	247%	225%	202%	322%	203%	258%
Gain Loss EWH		- 34.23	- 26.17	- 23.60	- 49.85	- 23.97	- 35.60
REVENUE		-Rp 329,109,412.29	-Rp 252,809,470.43	-Rp 229,470,639.88	-Rp 495,647,244.66	-Rp 232,508,065.42	-Rp 343,017,203.80
AVERAGE ACH SLIPPERY JANUARI - JUNI		243%					
AVERAGE GAIN LOSS REVENUE JANUARI - JUNI		-Rp 313,760,339.41					

Figure 1. Average Achievement Slippery Path Pit to ROM Period January–June 2025

Operational data shows that during the period from January to June 2025, the achievement slippery on the Pit to ROM road averaged 243%, or equivalent to 1.83 hours of production stoppage every time it rained. This value far exceeds the company's tolerance limit of 0.75 hours (100%). The high slippery hours cause significant disruption to the basalt getting production target and contribute to an average monthly income loss of IDR 313,760,339.

In addition to the high value of slippery, another problem identified is the incompatibility of road geometry. Some road segments have a width of less than 12 meters and a grade of more than 8%, which is not in accordance with the provisions of the Ministry of Energy and Mineral Resources No. 1827 K/30/MEM/2018. This condition increases the risk of slippage and loss of control in the hauling unit, especially when carrying a full load in wet road conditions. Based on the results of the road condition assessment using the Unpaved Road Condition Index (URCI) method, the Pit to ROM route obtained a score of 36, which is included in the bad category. The URCI value indicates that the road surface has suffered significant damage, such as waves, waterlogging, and degradation of the surface layer. This condition is exacerbated by a drainage system that has not met standards, so that the flow of rainwater is not controlled and flows directly into the road body.

Cause-and-effect analysis and field verification identified that the root of the problem of high slippery hours was not only caused by weather factors, but also by the absence of hard materials as the basis of the road, the systematic testing of the carrying capacity of the soil, and the absence of a monitoring system and special units for haul road maintenance. Therefore, the solutions implemented must be able to solve all these problems in an integrated manner. The main solution implemented in this study is the use of reject crusher material as a road base layering material (Segui et al., 2023; Mashaan & Yogi, 2025). Reject crusher material is a by-product of the basalt crushing process which has no economic value and is only a waste material that requires area disposal. Physically, this material has a mixture of rock fractions and fine materials that can increase the bonding strength and roughness of the road surface after being properly compacted (Durante Ingunza et al., 2020).

The implementation of the solution is carried out through several technical stages, including stripping of existing slippery materials, spreading reject crusher materials evenly, gradual compaction using compactors, and normalization of the drainage system so that rainwater flow does not inundate the road body. To ensure the quality of repair, a Dynamic Cone Penetrometer (DCP) test was carried out to determine the increase in the California Bearing Ratio (CBR) value of the subsoil and road layer after layering (Garcia et al., 2024; Elyasi et al., 2024). The selection of reject crusher material as an improvement solution is based on several main considerations, including the abundant availability of materials as a by-product of the crusher process, has no selling value so that it does not interfere with the main production, has physical characteristics that are able to reduce the level of road slippery, supports the reduction of the volume of waste materials in the disposal area, and has a lower cost than the use of new aggregate materials from the quarry (Yılmaz et al., 2018; Mehrjardi et al., 2020).

Based on this background, this study aims to analyze the effectiveness of the use of reject crusher material as a layering material in controlling slippery conditions on the Pit to ROM Pit Basalt PPA mining road. This research also aims to evaluate its impact on improving the performance of mining roads, work safety, as well as the company's production and financial performance. In terms of novelty, this research offers an alternative approach to repairing mining roads by utilizing by-product materials that were previously considered waste. The integration between technical testing (DCP), economic considerations, and environmental aspects makes this solution different from conventional practices that rely on overburden materials or new aggregates. These findings broaden the perspective that resource constraints can be overcome through field-condition-based innovation.

The main contribution of this research is to provide empirical proof that by-product materials that were previously considered waste can be effectively utilized as an economical, safe, and sustainable technical solution in mining road management. The results of this study are expected to be a practical reference for the management of mining roads in other locations with similar conditions and support the implementation of more efficient and sustainable mining practices.

METHOD

This study is an applied improvement study that is problem-solving oriented with the Quality Control Project (QCP) approach. The research was conducted as an operational case study on the Pit to ROM Pit Basalt hauling line of PT Putra Perkasa Abadi Site Maruwai with a quasi-experimental approach through a comparison of conditions before and after the implementation of the solution. The research stages include problem identification, root cause analysis, formulation and implementation of improvements, and evaluation of results using the company's actual operational data.

The object of the research is a ±2.8 km long mining road which serves as the main route for transporting basalt materials to the ROM crusher. The data used consisted of primary and secondary data, which were obtained through field observation, soil carrying capacity testing using the Dynamic Cone Penetrometer (DCP) method, technical evaluation of road geometry and drainage systems, as well as documentation of slippery achievement data, hauling unit performance, unit availability, and financial data before and after implementation. The research was carried out in the period from July to November 2025 involving the Department of Engineering and Production.

The main variable analyzed was the duration of the mining road slippery measured in hours of production stoppage due to slippery road conditions after rain, with supporting variables in the form of road geometry conditions, road surface quality, drainage system, and road base materials. Data analysis was carried out descriptively, quantitatively, and qualitatively through a comparative before-after approach, supported by cause-and-effect analysis and Pareto to ensure the effectiveness of solutions in reducing slippery hours, improving operational performance, and improving mine road safety aspects.

RESULTS AND DISCUSSION

Problem Identification

The results of the study began with the identification of the actual condition of the Pit to ROM hauling road to compare the situation that occurred in the field with the ideal conditions according to the mining road standards. This stage aims to obtain an initial overview of the level of gap that is the cause of the high duration of slippery and hauling operational disruptions.

Table 1. Problem Object Overview

No.	Actual situation occurs	Situations that should have happened	Remarks (OK/Not OK)
1	There are segments with a width of less than 10 m	Road width more than 10 m	NOT OK
2	Road grade More than 8%	Road grade less than 8%	NOT OK
3	No soil carrying capacity testing yet	The existence of soil carrying capacity testing	NOT OK
4	Rainwater runoff leads to the road body	There is drainage that drains rainwater	NOT OK
5	Not yet allocated a special excavator unit for mine road maintenance	Allocation of excavator units for mine road maintenance	NOT OK

6	There is no hard material in the pit that can be used for road construction	Utilization of pit materials to be used as a road base	NOT OK
7	There has been no socialization related to the calculation of slippery	GL Production knows and understands slippery calculations	OK

Table 1. indicates that most of the actual conditions of the mine road have not met the required standards. It was found that some road segments were less than 10 meters wide and graded exceeding 8%, which directly increased the risk of slippage in the hauling unit. In addition, the soil carrying capacity test has not been carried out, causing the quality of the road base to be uncontrolled and easily damaged when conditions are wet. Another significant problem is rainwater runoff that leads directly to the road body due to a non-standard drainage system, as well as the lack of allocation of special excavator units for mining road maintenance. The absence of hard materials in the pit area is also the main obstacle in road repairs. Of the seven conditions reviewed, six were declared non-conforming (Not OK), indicating that the slippery problem is systemic and not caused by a single factor.

Based on the results of the identification, the analysis was continued with the mapping of cause-and-effect relationships to determine the factors that contribute to the high achievement slippery. This analysis is presented in the form of a fishbone diagram.

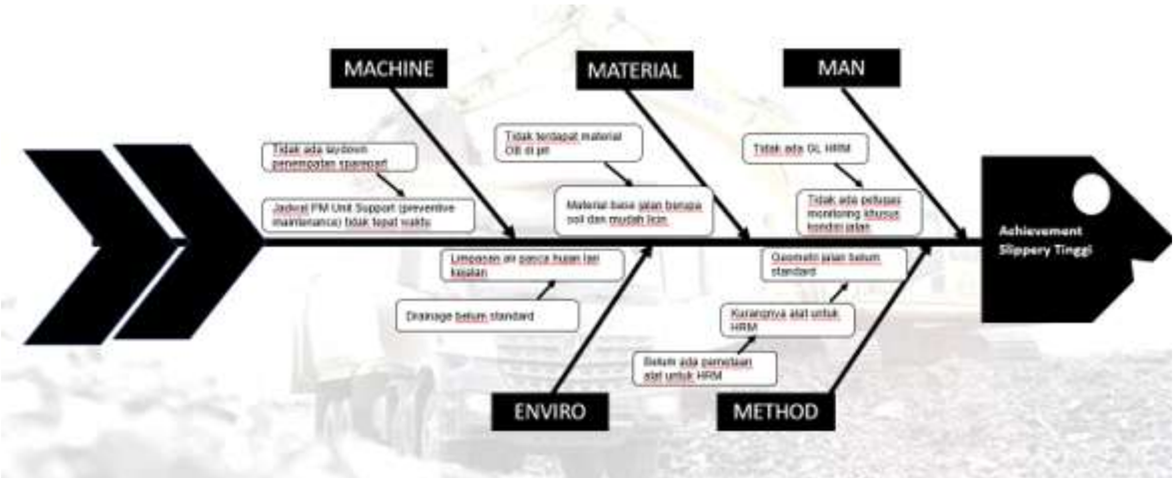

Figure 2. Cause-and-Effect Analysis of High Achievement Slippery

The results of the analysis showed that all identified factors were classified as the dominant root causes. Wide conditions and non-standard road grades have been proven to limit the movement of hauling units and increase the risk of slipping. The absence of soil carrying capacity testing causes the base of the fast road to be damaged, especially when it rains. A non-standard drainage system exacerbates slippery conditions as water runoff flows into the road body. The absence of a maintenance-specific excavator unit slows down the repair response, while the unavailability of hard materials in the pit hinders the formation of a stable road base. In addition, the lack of socialization of slippery calculations also contributes to the lack of optimal control of road conditions.

To ensure the degree of dominance of each of these factors, a root cause analysis is carried out through verification of actual conditions and comparison with ideal standards.

Table 2. Determining the Dominant Root Cause

No	Problem Identification	Verify current condition	Standard/Ideal Conditions	Conclusion (Dominant/Non-Dominant)
1	There are segments with a width of less than 10 m	Segments of less than 10 meters cause the road to only be passable by 1 DT unit	Road widening with a width of 12 meters so that DT can cross paths when the B/D unit is on the road	Dominant
2	Road grade More than 8%			Dominant
3	No soil carrying capacity testing yet	There is no soil carrying capacity test so that the road base is always damaged	Conducting soil testing so that the road can be said to be feasible, safe and comfortable	Dominant
4	Rainwater runoff leads to the road body	Rainwater runs onto the road until the slippery is high	Rainwater runoff into the road body	Dominant
5	Not yet allocated a special excavator unit for mine road maintenance	There is no dedicated excavator unit for mine road maintenance	Allocation of 1x PC200 specifically for mine roads	Dominant
6	There is no hard material in the pit that can be used for road construction	There is no material that can be used as a road base in the pit	Layering the base of the road using the Reject Crusher	Dominant
7	There has been no socialization related to the calculation of slippery	Socialization related to slippery calculation	GL production understands slippery calculation	Dominant

This table presents the results of verification of each of the main problems identified in the field. The results of the analysis showed that all the factors tested were classified as the dominant root causes. Road segments with a width of less than 10 meters have been proven to limit the movement of two dump truck units that cross paths, so they do not meet the ideal standard of 12 meters wide. Road grades exceeding 8% increase the risk of slipping in the hauling unit, especially when it rains. The absence of soil carrying capacity testing causes the road base to not have clear technical parameters related to feasibility and safety. Rainwater runoff leading to the road body shows that the drainage system has not been functioning optimally. The absence of a special maintenance excavator unit allocation and the absence of hard materials in the pit reinforce the need for an alternative solution in the form of road base layering using reject crusher material. In addition, the lack of optimal socialization of slippery calculations emphasizes the need to strengthen managerial aspects and operational understanding.

Solution Formulation

Based on the results of the identification of the dominant root cause, the formulation of solutions is focused on efforts that are able to reduce the duration of slippery effectively by considering technical aspects, cost, and ease of implementation. Alternative solutions are prepared by evaluating the opportunity for results, time needs, and cost impacts so that the chosen solution is applicable and sustainable.

Table 3 shows that the addition of a special excavator unit for road maintenance haul has technical potential, but it was not chosen because it requires considerable additional costs. Meanwhile, road repairs according to URCI standards by optimizing scheduled PC200 units and spreading reject crusher material are considered more effective and efficient. Both alternatives were chosen because they can be implemented without the addition of new heavy equipment and support the standardization of mining roads.

Table 3. List of Alternative Solutions

No.	List of Alternative solutions	Analysis of Considerations				Options (Selected / No)
		Yield opportunities	Time	Cost	Other considerations	
1	Adding 1 x Excavator Unit for HRM			IDR 108,009,000		×
2	Carry out road repairs according to URCI standards using a scheduled support unit (PC200)				Standardization of roads according to URCI by mapping the PC200 priority scale to be used by general HRM	✓
3	Material Rejection Crusher				Improve by layering using reject crusher material	✓

Based on the results of the evaluation, the best solution determined is the use of reject crusher material as the basis material for the road. This material is a by-product crusher that has no economic value, is widely available, and has physical characteristics that are able to increase carrying capacity and reduce slippery conditions after compacting. Implementation is carried out through stripping of existing slippery materials, stretching and compaction of rejected materials, and improving drainage in critical segments. To minimize risks, material selection, support unit schedules, and monitoring of post-rain road conditions are carried out, so that the effectiveness of repairs can be maintained consistently.

Fix implementation

The improvement plan is prepared in detail as shown in Table 4. Repair activities began with the identification and mapping of areas with high slippery levels, followed by the scheduling of PC200 units for haul road maintenance, drainage system repairs, and replacement of poor road surface materials using reject crusher materials. The material is then spread and compacted gradually, followed by a trial using a dump truck unit and monitoring the duration of the slippery after rain. The intermediate goals of this series of activities are to reduce the potential for slippage incidents, reduce near misses, improve operator safety, reduce slippery hours, and increase hauler unit availability.

Table 4. Improvement Plan

No.	Root cause (WHY)	Solution activity (HOW)	Documents	Intermediate Targets (WHAT)
1.	High slippery time after rain because road conditions are not ideal	1. Identification and mapping of slippery height areas 2. Scheduling PC200 for HRM 3. Drainage Repair 4. Replace ugly material with reject crusher material 5. Spreading the reject crusher material to the high slippery area 6. Compacting the area that has been spread with rejected material 7. Trial using DT units 8. Monitoring the Duration of Slippery After Rain 9. Standardization when successful	• MOC_AWR_BASALT_PPA_MAC • COST & REVENUE Slippery Basalt Mining	1. Lowers the potential incident of slip units 2. Reduce near miss in slippery areas. 3. Improving the safety of road operators and users 4. utilize waste (Reject Crusher) so that **cost savings** are achieved 5. Lowering the slippery clock after the rain 6. Upgrading UA Unit Hauler
			Person in Charge (WHO) :	Haryadi Indrianto
			WHERE: Mine	Road Pit To ROM
			Waktu (WHEN) :	June 2025
			Estimated cost (HOW MUCH) :	-
2.			Documents	Intermediate Targets (WHAT)
			Person in Charge (WHO)	
			Tempat (WHERE)	
			Waktu (WHEN)	
			Estimated cost (HOW MUCH)	

To ensure effective implementation, a repair team was formed with a clear division of roles as shown in Table 5. The team leader is responsible for coordinating overall activities and strategic decision-making, while the secretary plays a role in managing communication and project administration. Other team members are directly involved in unit coordination, fieldwork execution, as well as technical testing such as soil carrying capacity testing using DCP. This cross-functional engagement ensures that solutions are not only technical, but also integrated with operational needs.

Table 5. Implementation of Improvement Plan

No.	Scope of Job Activities	Personnel Name	Competencies	Remarks
1	Team Leader	Haryadi Indrianto	• Coordinating the overall project activities	GL. STAFF

No.	Scope of Job Activities	Personnel Name	Competencies	Remarks
			• Setting work plans and improvement targets • Make strategic decisions related to Solutions • Communicate with management	
2	Secretary	Kurnia Subandana	• Become a communication liaison between team members and stakeholders • Scheduling meetings, presentations, and evaluations • Submit meeting invitations and official team information	GL. STAFF
3	Members	Agus Muji Widodo	Coordinating A2B units to carry out project activities	GL. STAFF
4	Members	Denny Septian	Prepare data and perform DCP testing on predefined areas	Non Staff
5	Members	Ade Septian	Prepare data and perform DCP testing on predefined areas	Act. GL

In terms of resource readiness, all implementation needs are stated to be met as shown in Table 6. The availability of reject crusher materials, supporting heavy equipment units, DCP test equipment, and maintenance signs allows repairs to be carried out without significant obstacles. The readiness of this resource is the main supporting factor for the successful implementation of improvements in controlling slippery conditions on Pit to ROM hauling roads.

Table 6. Preparation of Required Resources

No.	Resources Required	Quantity	Fulfilled/Unfulfilled	Remarks
1	Material Reject Crusher	1900 m3	Fulfilled	
2	Dump Truck	2 Unit	Fulfilled	
3	Excavator PC200	1 Unit	Fulfilled	
4	Degrees	1 Unit	Fulfilled	
5	Compact	1 Unit	Fulfilled	
6	Dozer	1 Unit	Fulfilled	
7	DCP Measuring Instruments	1 Set	Fulfilled	
8	Rambu Maintenance	1 Set	Fulfilled	

Evaluation of Results

The evaluation of the results is carried out to assess the suitability between the improvement plan that has been prepared and the implementation in the field, as well as to measure the technical, operational, and financial impact of the improvements implemented. This stage is the main indicator of the success of slippery control on Pit to ROM hauling roads.

The implementation of the improvement plan is shown in Table 7, which illustrates that all key activities have been implemented according to the plan. Activities include drainage repair and normalization, soil carrying capacity testing using DCP, spreading and compaction of reject crusher materials, to socialization of AWR roads and safety aspects to road users. This consistent and integrated implementation ensures that improvements focus not only on the road surface, but also on technical aspects and operational behavior.

Table 7. Implementation of Improvement Plan

No	Repair Activities	Implementation of Improvements	Documentation
1	Excavator repairs drainage		
2	DCP Testing		
3	Dozer Spreads Reject Material		
4	Unit Dump Truck Dumping material Reject		
5	Unit Grader Spreads reject material		

6	Compact unit performs compaction	
7	Material Reject Crusher	
8	Socialization of AWR and Safety Friendly Roads	
9	Excavator Loading Material Reject Crusher	

Furthermore, the evaluation of value added is shown in Figure 3, which illustrates the contribution of improvement to improving operational performance. The implementation of layering with reject crusher material provides added value in the form of reducing production stop hours, improving road safety, and utilizing waste materials into functional materials, thus providing dual benefits for mine operations.

WEATHER		Jul-25	Aug-25	Sep-25	Oct-25	Nov-25
Rain	Plan Rain	71.97	82.93	71.14	173.29	196.08
	Actual Rain	89.83	132.82	115.57	77.62	98.77
	ACV	125%	160%	162%	45%	50%
Slippery	Plan Slip	23.25	46.50	22.50	23.25	45.00
	Actual Slip	21.17	27.62	12.70	6.67	17.90
	ACV	91%	59%	56%	29%	40%
Gain Loss EWH		2.08	18.88	9.80	16.58	27.10
REVENUE		Rp 20,048,497	Rp 181,971,183	Rp 95,679,581	Rp 162,731,416	Rp 265,930,936
TOTAL REVENUE JULI - NOVEMBER		Rp 726,361,613				

Figure 3. Value Added Assessment of Improvement Implementation

From a financial perspective, the cost and benefit evaluation shows that during the period from July to November 2025, a total revenue gain of IDR 726,361,613 was obtained. This increase in revenue occurred because the duration of slippery was successfully reduced below the plan limit (<100%), so that effective working hours of hauling units increased and production losses could be minimized.

Table 8. Comparison of Slippery Conditions Before and After Improvement

Parameter	**Before Improvement**	**After Improvement**
Average slippery	243% (1.83 hours)	59% (0.5 hours)

URCI Value	36	Increased (eligible category)
UA Unit Hauler	Low	Increase
Safety risks	Height	Significant decline

The results of the technical evaluation showed a significant decrease in the duration of slippery after the implementation of the solution. In the period from July to October 2025, the average slippery fell to 59% or the equivalent of 0.5 hours, well below the company's tolerance limit. A comparison of conditions before and after the improvement is presented in Table 8, which shows an increase in the URCI value to a viable category, an increase in Unit Availability (UA) of hauler units, and a significant reduction in safety risks. These findings confirm that the solutions applied are effective in improving the performance of mining roads.

The slippery problem that occurred on the Pit to ROM hauling road in the early 2025 period shows that operational disruptions are not solely caused by weather factors, but are the accumulation of road technical conditions that do not meet standards, limited base materials, and a road maintenance system that is not optimal. The initial conditions characterized by low URCI values and high slippery duration confirm that the quality of the mine road has a crucial role in maintaining production continuity.

The selection of a solution in the form of the use of reject crusher material as a road base layering material is based on technical, economic, and operational considerations. Reject crusher material is available in abundance as a by-product of the crushing process, has no selling value so that it does not interfere with production targets, and has physical characteristics in the form of a mixture of rock fractions and fine materials that are able to increase the bonding power of the road surface and reduce slippery potential. In addition, the utilization of these materials supports the reduction of waste volume in the disposal area and provides cost efficiency because it is more economical than the use of new aggregate materials from the quarry (Yılmaz et al., 2018; Mehrjardi et al., 2020; Segui et al., 2023; Mashaan & Yogi, 2025). The implementation of improvement is carried out through structured stages, starting from the identification of road segments with a high level of slippery, dredging of existing slippery materials, spreading reject crusher material evenly, and compaction of layers using compactors until they reach a density that meets mining road standards. The final stage is in the form of monitoring road conditions after rain and after heavy equipment has been passed to ensure the stability and sustainability of repair results.

The results showed that after the implementation of material rejection crusher layering and normalization of the drainage system, there was a significant decrease in slippery duration. In the period from July to October 2025, the average achievement slippery fell to 59% or equivalent to 0.5 hours, well below the company's tolerance limit. This decrease indicates that the solutions implemented are effective in answering the root of the main problem causing slippery, especially the limited carrying capacity of the road surface and the poor rainwater flow.

From an operational perspective, the reduction in the duration of slippery has a direct impact on increasing the effective working hours of hauler units. The hauling unit can operate more consistently with minimal disruption, so that the production rhythm becomes more stable. Improved road conditions also contribute to the stability of hauling speeds, reduced fuel consumption, and reduced workloads on the machine's braking and suspension systems. These findings confirm that the quality of mining roads is a key variable in maintaining production continuity and operational efficiency (Suhendar et al., 2024; Hia et al., 2025).

From a financial perspective, slippery control contributes significantly to the increase in the company's revenue. Data shows a revenue gain of IDR 460,430,676 in the July-October 2025 period, as well as a total revenue of IDR 726,361,613 in the July-November 2025 period due to slippery that was successfully suppressed under the <100% plan. When compared to the condition before improvement, where the company experienced an average revenue loss of IDR 313,760,339 per month, the implementation of this solution can be categorized as an operational investment with a very high rate of return. In addition, the use of reject crusher materials also reduces the need to purchase new materials and rehandling activities from outside the pit, thereby reducing indirect costs (Iqbal et al., 2025).

The occupational safety aspect also showed significant improvements. After road repairs were carried out, segments with a grade of more than 8% no longer experienced slippery conditions, and no unsafe conditions (KTA) were found along the Pit to ROM route. The reduction in the potential for near miss and the risk of hauling accidents is an indicator that improving road quality has a positive impact on work safety (Hoebbel et al., 2024). In addition, the improvement in road conditions also has an impact on the work morale of operators. Hauler unit operators and support units feel an increased sense of safety and comfort while working, as well as a decrease in fatigue levels, which reflects improved working conditions and overall human resource performance.

These findings confirm that slippery control through a structured improvement approach can provide multidimensional benefits, including increased productivity, cost efficiency, work safety, and operational sustainability. The results of this study reinforce the importance of mining road quality management as a strategic element in a safe and sustainable mining system.

CONCLUSION

The main findings show that the use of reject crusher material as a road layering material, combined with drainage improvement, soil carrying capacity testing using DCP, and the allocation of special units for haul road maintenance, is able to significantly reduce the duration of slippery to below the planned limit (<100%). This implementation has a direct impact on increasing the effective working hours of hauler units, increasing unit availability, improving road safety conditions, and generating revenue gains that are cumulatively worth hundreds of millions of rupiah. In addition, non-financial aspects such as operator comfort, reduced risk of accidents, and improved work morale are also real. The study's main contribution to mine improvement practices and literature is the proof that by-product materials that were previously considered waste can be effectively utilized as an economical, safe, and sustainable technical solution for slippery control. However, this study has limitations because it was conducted at a single mine site with specific material characteristics and geographical conditions, so generalization of results needs to be done carefully. For further research and improvement, it is recommended to conduct comparative testing with alternative materials, the application of a road monitoring system based on digital technology or drones, and a long-term sustainability analysis of the performance of mining roads to ensure that repair results can be maintained consistently.

REFERENCES

Alawi, A. Z., & Setiaji, W. S. (2022). Analysis of the suitability of grade parameters, angle of turn, and width of pit mine roads to ensure the safety and security of the mine unit using aerial photographic data. *Journal of Marine-Earth Science and Technology, 3*(2), 49–54.

Berberoglu, Y., Mangla, S. K., & Kazancoglu, Y. (2024). Towards sustainable mining in an emerging economy: Assessment of sustainability challenges. *Resources Policy, 97*, 105288.

Chen, Z., Yang, Y., Zhou, L., Hou, H., Zhang, Y., Liang, J., & Zhang, S. (2022). Ecological restoration in mining areas in the context of the Belt and Road Initiative: Capability and challenges. *Environmental Impact Assessment Review, 95*, 106767.

Durante Ingunza, M. D. P., dos Santos Júnior, O. F., & Gerab, A. T. F. D. S. C. (2020). Potential use of sandy mining wastes as raw material in road construction. *Geotechnical and Geological Engineering, 38*(5), 5681–5691.

Elyasi, M. R., Daryaee, D., & Sarabi, F. (2024). Presenting a CBR estimation model and compaction characteristics of base layer of pavement using a dynamic cone penetrometer (DCP) test. *Journal of Testing and Evaluation, 52*(4), 2335–2349. https://doi.org/10.1520/JTE20230157

Garcia, K. E., Cruz, O. G. D., Muhi, M. M., & Tabaroei, A. (2024). The role of dynamic cone penetrometer testing in assessing pavement subgrade strength: A literature review. *GEOMATE Journal, 26*(117), 132–142.

Hia, S. W., Singgih, M. L., & Gurning, R. O. S. (2025). The application of lean six sigma to improve mining transportation overall vehicle effectiveness (MTOVE): A case study in a mining company. *International Journal of Lean Six Sigma, 16*(1), 54–88. https://doi.org/10.1108/IJLSS-07-2023-0121

Hodge, R. A., Ericsson, M., Löf, O., Löf, A., & Semkowich, P. (2022). The global mining industry: Corporate profile, complexity, and change. *Mineral Economics, 35*(3), 587–606.

Hoebbel, C. L., Bellanca, J. L., & Hrica, J. K. (2024). Lessons learned from haul truck operator near-miss events: Use of the critical decision method to identify strategies to improve operator safety in mining. *Mining, Metallurgy & Exploration, 41*(5), 2245–2255.

Iqbal, A., Mashaan, N. S., & Paraskeva, T. (2025). Mining waste in asphalt pavements: A critical review of waste rock and tailings applications. *Journal of Composites Science, 9*(8), 402. https://doi.org/10.3390/jcs9080402

Jiang, J. (2025). *Efficient detection of road surface disruptions for off-road mining trucks* (Master's thesis). University of Guelph.

Joe-Asare, T., Stemn, E., & Amegbey, N. (2023). Causal and contributing factors of accidents in the Ghanaian mining industry. *Safety Science, 159*, 106036. https://doi.org/10.1016/j.ssci.2022.106036

Kolapo, P., Oniyide, G. O., Said, K. O., Lawal, A. I., Onifade, M., & Munemo, P. (2022). An overview of slope failure in mining operations. *Mining, 2*(2), 350–384.

Mashaan, N., & Yogi, B. (2025). Mining waste materials in road construction. *Encyclopedia, 5*(2), 83. https://doi.org/10.3390/encyclopedia5020083

Mehrjardi, G. T., Azizi, A., Haji-Azizi, A., & Asdollafardi, G. (2020). Evaluating and improving the construction and demolition waste technical properties to use in road construction. *Transportation Geotechnics, 23*, 100349. https://doi.org/10.1016/j.trgeo.2020.100349

Milošević, I., Stojanović, A., Nikolić, Đ., Mihajlović, I., Brkić, A., Perišić, M., & Spasojević-Brkić, V. (2025). Occupational health and safety performance in a changing mining environment: Identification of critical factors. *Safety Science, 184*, 106745.

Sadeghi, P., & Goli, A. (2024). Investigating the impact of pavement condition and weather characteristics on road accidents. *International Journal of Crashworthiness, 29*(6), 973–

989. https://doi.org/10.1080/13588265.2024.2348269

Segui, P., Safhi, A. E. M., Amrani, M., & Benzaazoua, M. (2023). Mining wastes as road construction material: A review. *Minerals, 13*(1), 90. https://doi.org/10.3390/min13010090

Suhendar, A. D., Nurmansyah, A., Pramuditha, P., & Santo, E. (2024). Operations management in measuring the operational effectiveness and efficiency in companies engaged in the mining industry. *JURISMA: Jurnal Riset Bisnis & Manajemen, 14*(2), 329–340. https://doi.org/10.34010/jurisma.v14i2.12855

Terziyski, D. (2024). Optimization of technological schemes for construction of open mine roads. *Proceedings of the Bulgarian Academy of Sciences, 77*(1), 101–110. https://doi.org/10.7546/CRABS.2024.01.12

Yıldız, T. D. (2021). Loss of profits occurring due to the halting of mining operations arising from occupational accidents or reasons related to legislation. *Gospodarka Surowcami Mineralnymi, 37*. https://doi.org/10.24425/gsm.2021.139739

Yılmaz, T., Ercikdi, B., & Deveci, H. (2018). Utilisation of construction and demolition waste as cemented paste backfill material for underground mine openings. *Journal of Environmental Management, 222*, 250–259. https://doi.org/10.1016/j.jenvman.2018.05.075