

Risk Analysis Of Ship Hatch Cover Operations Using Bowtie Analysis At Koja Container Terminal

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Abstract

Hatch cover opening and closing is an operational activity in container terminals that involves interaction between lifting equipment, personnel, and ship components, creating potential operational risks. This study aims to analyze the risk of hatch cover collision with surrounding objects during hatch cover opening and closing at Koja Container Terminal (TPK Koja), identify its contributing factors and consequences, and map the existing preventive and mitigative barriers. A descriptive qualitative approach was employed using incident reports from 2020-2025, semi-structured interviews, field observations, and company documentation. Data were analyzed using Bowtie Analysis to systematically map the relationships between threats, top events, consequences, and risk barriers. The results identified hatch cover collision with objects around the hatch cover on the ship deck as the top event. The contributing factors consisted of communication disturbances, limited visibility, suboptimal QCC components, non-compliance with procedures, worker conditions, and unfavorable weather and environmental conditions. The consequences included damage to surrounding objects, reduced QCC performance, and temporary suspension of cargo handling when hatch locking components were damaged. This study provides an integrated qualitative risk mapping of hatch cover operations through the identification of casual factors, consequences, and preventive and mitigative barriers.

Keywords: Bowtie Analysis, Hatch Cover, Risk Analysis, Container Terminal, Risk Barrier

INTRODUCTION

Container terminals are complex operational environments involving continuous interaction between cargo handling equipment, workers, vessels, and supporting facilities. The intensity of these activities creates various operational risks that may affect safety and operational continuity. Koja Container Terminal (TPK Koja) operates container handling activities continuously and is supported by equipment such as Quay Container Crane (QCC), Rubber Tyred Gantry (RTG), and other cargo-handling equipment. The

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increasing intensity of container handling also requires effective risk management in operational activities involving heavy equipment and human interaction. Based on the 2025 operational data presented in the research site, container handling at TPK Koja reached 1,058,466 TEUs.

Table 1. Number of Incidents (2020-2025) During Hatch Cover Operations and Container Loading/Unloading

Jenis Aktivitas	Jumlah Insiden						Jumlah
	2020	2021	2022	2023	2024	2025	
Buka dan tutup palka	15	18	10	27	12	13	95
Bongkar muat peti kemas	5	5	13	9	6	6	44
Total Insiden							139

Based on table 1, One of the operational activities identified as having a considerable number of incidents is hatch cover opening and closing. Analysis of company incident reports for 2020-2025 recorded 95 incidents related to hatch cover opening and closing, compared with 44 incidents related to container handling. Further classification showed that 61 incidents involved safety railings, 12 involved hatch locking components, 44 involved lashing bars, 3 involved incoming hatch covers, 3 involved hatch cover guides, 3 involved gangways, and 9 involved other objects. These findings indicate frequency but also by examining how the incidents may occur, their consequences, and the barriers available to prevent or mitigate them.

Previous studies have examined risk in port and terminal operations using different approaches. Yanarko and Basuki (2021), for example, applied Bowtie Risk Assessment to operational risks at Berlian Port and identified weather conditions, operator fatigue or lack of concentration, and inadequate safety signs as contributing factors. Haerul at al. (2024) examined hazards and risks in loading and unloading activities at PT Pelindo IV Balikpapan using qualitative observation and interviews, including hazards associated with opening and closing vessel hatches. More recently, Hendri et al. (2025) also examines a broader range of cargo-handling accident risks. Thus, a more specific analysis focusing on the hatch cover opening and closing process and its collision mechanism is still relevant. In addition, the preliminary analysis conducted by TPK Koja used fishbone analysis to identify causal factors of incidents. However, the existing analysis did not comprehensively map the relationship between causes, consequences, and barriers associated with the risk.

LITERATURE REVIEW

Risk Management and Bowtie Analysis

Risk analysis is conducted to understand the characteristics of risk by considering its causes, potential consequences, and relevant control measures. Within the risk management framework based on SNI ISO 31000:2018, risk assessment includes risk identification, risk analysis, and risk evaluation. This study focuses on risk identification and analysis and does not perform risk evaluation or determine organizational risk acceptance and prioritization. Bowtie Analysis is a qualitative risk analysis method that represents the relationship between threats, a top event, consequences, and barriers in a single visual framework. The left side of the Bowtie represents preventive barriers that function to prevent threats from developing into the top event, while the right side represents mitigative barriers that reduce or limit consequences after the top event occurs. Aust and Pons (2019) demonstrated the use of Bowtie Analysis to identify hazards, threats, consequences, and barriers through interviews and observation in a maintenance context.

The application of Bowtie Analysis in port operations has also been demonstrated by Yanarko and Basuki (2021), who used the method to assess operational risks at Berlian Port. Their findings indicate that operational risk can arise from interactions between environmental conditions, operator conditions, and existing safety controls. Hendri et al. (2025) further demonstrated the use of Bowtie Analysis in identifying and mitigating occupational accident risks in port cargo-handling activities. Based on these studies, the position of the present research is to apply Bowtie Analysis specifically to the hatch cover opening and closing process at a container terminal. Rather than assessing overall terminal risk, this study focuses on one recurring operational event, namely the collision of hatch covers with surrounding objects, and maps its causal pathways, consequences, and barriers in an integrated framework.

RESEARCH METHOD

This study employed a descriptive qualitative approach. The qualitative approach was selected because the research aimed to obtain an in-depth understanding of the factors contributing to hatch cover collision incidents and the control measures applied in the operational context of TPK Koja. The research data consisted of primary and secondary data. Primary data were obtained through semi-structured interviews and field observations, while secondary data were obtained from company incident reports and supporting operational documentation for the 2020-2025 period. The informants consisted of three personnel representing different operational and safety functions: Samson Sinagar as Supervisor Safety Management System in HSE, Bowo Sulystiantoro as Operational Support personnel in PPG, and Anas as PPG Supervisor.



Data collection was conducted through interviews, observations, and documentation. Interviews were used to identify causal factors, operational conditions, consequences, and existing controls. Observations were conducted to understand the hatch cover opening and closing process and the interaction between QCC operators and personnel involved in the operation. Company documentation, particularly incident reports, was used to identify the pattern of incidents during 2020-2025. Data credibility was strengthened through source triangulation by comparing information obtained from the three informants and verifying it through observations and company documentation. The three informants provided complementary information according to their respective roles, particularly concerning technical conditions, operational procedures, communication, and operational consequences. Data analysis was conducted using Bowtie Analysis. The analysis consisted of: (1) identifying the hazard and operational activity; (2) determining the top event based on incidents patterns; (3) identifying threats or contributing factors; (4) identifying consequences; (5) analyzing existing preventive barriers; (6) analyzing existing mitigative barriers; and (7) arranging the findings into a Bowtie framework. The top event was determined as the collision of the hatch cover with objects surrounding the hatch cover on the ship deck during opening and closing operations.

RESULT

Incident Pattern in Hatch Cover Operations

The analysis of TPK Koja incident reports for 2020-2025 identified 95 incidents associated with hatch cover opening and closing. These incidents involved unwanted contact, collision, or entanglement between hatch covers and objects surrounding the hatch area. Safety railing represented the largest category of affected objects, followed by hatch locking components and other supporting components.

Table 2. Objects Affected by Hatch Opening and Closing Operations at TPK Koja (2020–2025)

No	Objek Yang Terdampak	Frekuensi	Persentase
1	Safety railing	61	64,21%
2	Kunci Palka	12	12,63 %
3	Lashingbar	4	4,21%
4	Incoming Hatch Cover	3	3,16%
5	Hatch Cover Guide	3	3,16%
6	Gangway	3	3,16%
7	Objek lainnya	9	9,47%
TOTAL		95	100%

The incident pattern indicates that although the affected object vary, the incidents share a similar event mechanism: the hatch cover comes into contact with or collides with an object during lifting, movement, or placement. Based on this common mechanism, the collision of the hatch cover with surrounding objects was established as the top event in the Bowtie Analysis.

Bowtie Analysis of Hatch Cover Collision Risk

The Bowtie Analysis was used to illustrate the relationship between the contributing factors, top event, consequences, and control barriers associated with hatch cover collision during ship hatch cover opening and closing operations. The analysis integrates preventive barriers that act before the top event and mitigative barriers that function after the top event to reduce its potential consequences. The resulting risk pathway is presented in Figure 1.

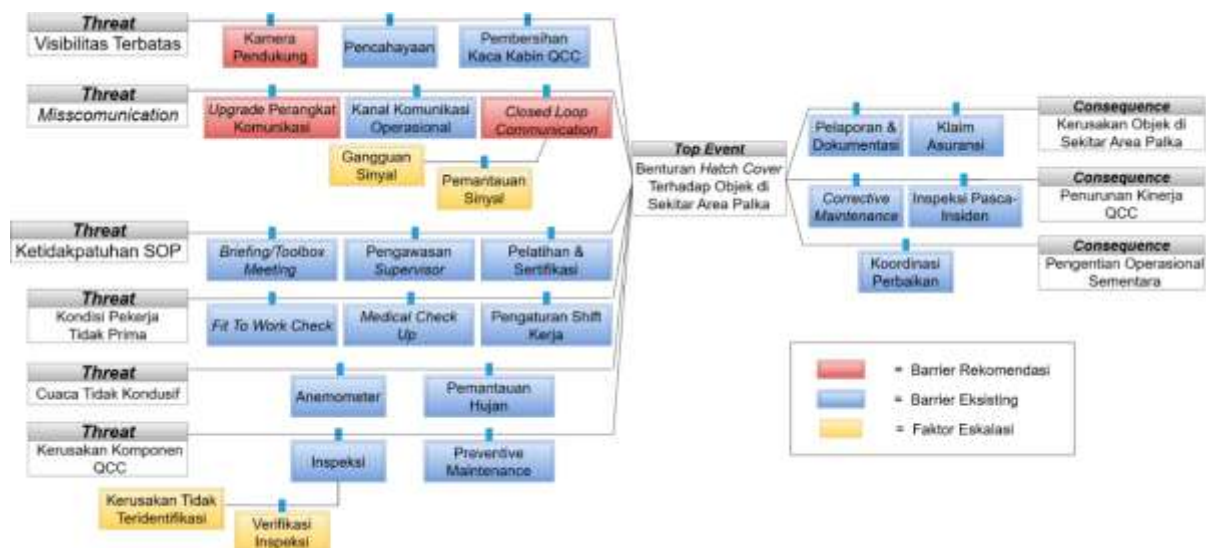


Figure 1: Bowtie Analysis of Hatch Cover Collision Risk During Hatch Cover Opening and Closing

As shown in Figure 1, the Bowtie Analysis identifies the following elements:

1. Threats / Contributing Factors

The identified contributing factors consist of communication disturbance, limited visibility, suboptimal QCC components, non-compliance with SOP, worker condition, and unfavorable weather or environmental conditions. These factors may increase the possibility of uncontrolled hatch cover movement or inaccurate coordination during the opening and closing process, thereby creating conditions that can lead to the top event.

2. Top Event

The top event in this analysis is defined as hatch cover collision with objects around the hatch cover area during the opening and closing process. This event represents the point at with surrounding objects.

3. Preventive Barriers

Preventive barriers are controls implemented to prevent the contributing factors from developing into the top event. Based on the research findings, these barriers include operational communication procedures and closed-loop communication, adequate lighting and QCC cabin window cleaning, routine inspection and preventive maintenance off QQCC components, toolbox meetings and competency training, fit to work check and periodical examinations, as well as monitoring of weather and environmental conditions.

4. Consequences

The occurrence of the top event may result in damage to surrounding objects, reduced QCC performance, and temporary suspension of cargo handling activities. The severity of the consequences depends on the object affected and the extent of damage resulting from the collision. Damage to hatch-locking components, in particular, may require repair before cargo handling can resume.

5. Mitigative Barriers

Mitigative barriers are controls applied after the top event has occurred to limit the resulting consequences. The identified measures include post-incident inspection and corrective maintenance for damaged objects, technical inspection and testing of QCC components after repair, and coordination with vessel personnel for the repair of damaged hatch-locking components. These measures are intended to restore equipment and operational conditions and minimize disruption to cargo handling activities.

Contributing Factors and Preventive Barriers

The analysis identified six main contributing factors: communication disturbances, limited visibility, suboptimal QCC components, non-compliance with SOPs, non-optimal worker conditions, and unfavorable weather and environmental conditions.

- a. Communication was identified as an important factor because the QCC operator has limited visibility of the entire hatch cover operating area and therefore depends on instructions from personnel involved in directing the operation. Communication during the operation uses handheld radio communication. The analysis also identified the need to maintain effective confirmation of instructions through closed-loop communication.
- b. Limited visibility may affect the operator's ability to observe the hatch cover and surrounding objects. Existing barriers include adequate operational lighting and

cleaning of the QCC cabin windows when dirt or condensation interferes with visibility.

- c. Equipment reliability is another important factor. The QCC components involved in controlling hatch cover movement must remain operationally reliable. Existing preventive barriers include routine inspections and scheduled preventive maintenance, the company's maintenance activities are supported by maintenance documentation, while inspection and maintenance are intended to identify and address equipment conditions before they affect operations.
- d. Non-compliance with procedures was also identified as a contributing factor. Existing preventive barriers include toolbox meetings, competency training and certification, and supervision. Toolbox meetings are conducted before operational activities to communicate operational conditions, work assignments, potential hazards, and applicable procedures.
- e. Worker condition was addressed through fit to work check, periodic medical, check up, and shift arrangements. TPK Koja applies three work shifts of 07.00-15.00, 15-00-23.00, and 23.00-07.00 WIB, with regulated rest periods. These measures are intended to maintain worker readiness during continuous terminal operations.

Consequences and Mitigative Barriers

The Bowtie Analysis identified three main consequences of hatch cover collision: damage to surrounding objects, reduced QCC performance, and temporary suspension of cargo-handling operations.

- a. Damage to surrounding objects may require inspection and repair depending on the type and severity of the damage. Corrective actions are used to restore the affected component to an operationally safe condition.
- b. A collision involving QCC-related components may reduce equipment performance and require technical inspection before continued operation. Corrective maintenance consists of identifying affected components, determining appropriate repair actions, conducting repairs, and performing post-repair testing.
- c. The most significant operational consequence identified in the analysis occurs when the hatch cover collision damages the hatch locking mechanism. If the locking mechanism cannot function properly, cargo-handling activities involving the hatch cover may need to be temporarily suspended until the component is repaired and the hatch cover can be safely locked again. In this condition, coordination between vessel personnel and TPK Koja technical personnel becomes a mitigative barrier to accelerate recovery and enable operations to resume.

DISCUSSION

The findings demonstrate that hatch cover collision at TPK Koja is not associated with a single causal factor. The Bowtie structure shows an interaction between human, technical, environmental, operational, and procedural factors. This finding is consistent with previous port-risk studies that identify operational risks as arising from multiple interacting conditions rather than from a single failure mechanism. Yanarko and Basuki (2021), for example, identified weather conditions, operator conditions, and safety provisions as factors associated with operational risk at Berlian Port

The identification of communication disturbance as a threat is particularly relevant because hatch cover operations involve coordination between the QCC operator and personnel directing the movement. In this situation, communication is not merely an administrative procedure but forms part of the operational control system. The existence of communication procedures and closed-loop confirmation provides a preventive barrier because it is intended to ensure that instructions are received and understood before the movement is executed. However, the finding that the operator simultaneously has to control QCC movement and communicate through handheld equipment indicates that the effectiveness of the communication barrier is also influenced by the suitability of the communication system to the operational context. The study therefore positions communication effectiveness as a barrier that requires continuous strengthening rather than treating communication equipment alone as the solution.

The technical findings also demonstrate the importance of equipment reliability. Hatch cover movement depends on the ability of QCC components to respond accurately to operator commands. Existing routine inspections and preventive maintenance function as preventive barriers. This finding is consistent with Iskandar et al (2021), who examined reliability, availability, and maintainability of lifting equipment in port operations and emphasized the importance of equipment maintenance for operational continuity. Another important finding is that consequences differ according to the object involved and the resulting level of damage. The 95 incidents cannot therefore be interpreted only through their frequency. For example, safety railing accounted for 61 incidents, but damage to hatch-locking components may have a more direct operational consequence because the inability to lock the hatch cover can interrupt cargo-handling activities. This illustrates the value of Bowtie Analysis: the method allows the analysis to move beyond the question of how frequently an event occurs toward understanding the pathways through which an event may produce different consequences and how barriers function along those pathways.

The main contribution of this study is therefore the development of a specific qualitative risk representation for hatch cover operations in a container terminal. The resulting Bowtie framework provides an integrated view of how communication, visibility,



equipment condition, procedural compliance, worker condition, and environmental conditions may contribute to the top event, while also showing how inspection, maintenance, corrective actions, and operational coordination function as barriers after the event. This approach complements existing incident analysis by connecting causal factors with consequences and control measures in a single analytical framework.

CONCLUSION

This study identified the risk mechanism associated with hatch cover opening and closing at TPK Koja using Bowtie Analysis. Based on incident reports from 2020-2025, 95 incidents involving unwanted contact or collision between hatch covers and surrounding objects were identified. The common event mechanism was established as the top event, namely the collision of a hatch cover with objects surrounding the hatch cover on the ship deck. Six main contributing factors were identified: communication disturbance, limited visibility, suboptimal QCC components, non-compliance with SOPs, non-optimal worker conditions, and unfavorable weather and environmental conditions. Preventive barriers included communication procedures, closed-loop communication, adequate lighting, cabin-window cleaning, routine inspection, preventive maintenance, toolbox meetings, competency certification, supervision, worker fitness checks, medical examinations, and work-rest arrangements.

The identified consequences consisted of damage to surrounding objects, reduced QCC performance, and temporary suspension of cargo-handling operations when hatch-locking components were damaged. Mitigative barriers included post-incident inspection, corrective maintenance, post-repair testing, and coordination between TPK Koja and vessel personnel. The contribution of this study lies in providing an integrated qualitative mapping of a specific hatch cover collision risk rather than assessing terminal risks in general. The study is limited to risk identification and analysis and does not evaluate risk acceptance or quantitatively determine risk priority. Future research may therefore examine the effectiveness of the identified barriers using quantitative or mixed-method approaches.

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