

Operational Risk Control Strategies in Fuel Distribution Using Hirarc And FTA

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ABSTRACT

Safety in fuel oil (BBM) distribution is a top priority given the high risks that can occur, such as fires, spills, and accidents due to mechanical failures. This research analyses the factors that cause operational incidents at PT ABC, specifically truck operational accidents in fuel distribution, by applying the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) and Fault Tree Analysis (FTA) methods. Data collection was conducted through field studies and interviews with stakeholders, including drivers, mechanics, and logistics management. The results showed that the main causes of incidents included suboptimal vehicle maintenance, inappropriate tire pressure, driver fatigue, and brake system failure. Risk analysis showed that tire bursts had the highest risk level, with a score of 10 on the risk matrix. The implementation of risk control measures, such as daily inspections (P2H), the use of tire pressure gauges, and safety training for drivers, contributed significantly to lowering the number of operational incidents and improving on-time delivery. The implementation of stricter safety procedures resulted in improved operational efficiency at PT ABC, with a decrease in the number of incidents and the achievement of 100% on-time delivery by the final quarter of 2024. In conclusion, adherence to standard operating procedures (SOPs), regular vehicle maintenance, and increased driver safety awareness are key factors in creating a safer and more sustainable fuel distribution system.

KEYWORDS *Fuel Distribution; HIRARC; Fault Tree Analysis; Risk Control; Operational Safety*



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INTRODUCTION

According to the International Labour Organization (ILO), the global transportation and logistics sector records approximately 2.78 million occupational fatalities annually, with fuel transportation accounting for 12% of these incidents due to the hazardous nature of petroleum products (ILO, 2023; Zhao et al., 2021). In Indonesia, the Ministry of Manpower reported 174,878 workplace accidents in 2023, with the transportation sector contributing 23.4% of total incidents (Rahman et al., 2022; Susanto et al., 2021). Specifically, fuel distribution operations show alarming statistics, with Pertamina recording 127 operational incidents in 2023,

including 34 cases involving vehicle accidents, 28 fuel spillage incidents, and 65 equipment failures (Prasetyo & Utomo, 2020; Santoso et al., 2019). These statistics demonstrate that operational safety challenges in fuel distribution are not merely local issues but represent a critical global phenomenon requiring immediate attention and systematic intervention (Skripnik et al., 2020; Wulandari et al., 2022; Hidayatullah & Musyafa, 2015). Potential hazards such as fires, leaks, explosions, and fuel spills must be effectively managed (Purnomo et al., 2021), while the risk of workplace accidents in transportation also demands thorough hazard identification and control measures (Liu et al., 2020; Fang et al., 2022).

Consistent implementation of Standard Operating Procedures (SOPs), including pre-trip vehicle inspections and regular driver training, is essential to ensuring operational safety (Yuliantina et al., 2024). Evaluating and adhering to SOPs play a key role in reducing incident risks. A lack of compliance with SOPs has been shown to increase the likelihood of accidents and operational complications for companies (Hasugian & Lisdawati, 2016; Sinurat, 2022). Current operational data at PT ABC reveal critical safety deficiencies requiring immediate intervention. Between May and June 2024, the company recorded two tire blowout incidents resulting in a total operational downtime of 48 hours, direct repair costs of IDR 75 million, and additional compensation expenses of IDR 150 million for cargo delays and equipment damages. Annual incident frequency analysis shows a 15% increase in mechanical failures over the previous year, with monthly incident rates averaging 2.3 per 1,000 delivery trips. These operational losses translate to an estimated annual safety-related cost of IDR 2.4 billion, representing 8.7% of total operational expenses and significantly impacting the company's profitability and market reputation. Current conditions at the company indicate that incidents are still occurring, with two tire blowout incidents recorded (May and June 2024). This highlights weaknesses in the existing safety system. Internal company data show that these incidents have resulted in multiple losses, including lost operational time, financial losses due to repair costs and compensation for damages, and a decline in the company's reputation. These facts underline the urgent need for comprehensive improvements in PT ABC's operational safety system.

Previous research on operational safety in fuel distribution reveals significant gaps in systematic risk management approaches. Hasugian and Lisdawati (2016) emphasized the critical importance of Standard Operating Procedures (SOPs) in laboratory biosafety but found limited application in field operations. Sinurat (2022) demonstrated weak implementation of safety SOPs in workplace accident prevention, showing a disconnect between theoretical knowledge and practical application. Wong et al. (2022) successfully tested HIRARC effectiveness in dam construction projects, proving its applicability in large-scale operations, while Skripnik et al. (2023) established correlations between SOP compliance and

accident reduction in mining operations. However, these studies primarily focused on static industrial environments rather than dynamic transportation contexts. A critical research gap emerges: while existing literature validates individual components of safety management systems, no comprehensive study has specifically examined the integrated application of HIRARC and FTA methodologies in fuel distribution operations at PT ABC, where unique operational challenges including mobile equipment, varying route conditions, and time-sensitive delivery requirements create distinct risk profiles that demand specialized analysis and intervention strategies.

Empirical evidence from similar industries demonstrates the effectiveness of systematic risk management approaches. Research by Ghaleh et al. (2019) in hazardous material transportation showed that HIRARC implementation reduced incident rates by 65% over two years. Waskito et al. (2024) found that systematic vehicle maintenance protocols decreased mechanical failure rates by 48% in freight operations. Additionally, Reiman et al. (2018) demonstrated that comprehensive driver training programs reduced human error incidents by 52% in logistics operations. These studies provide strong empirical foundations for implementing integrated HIRARC and FTA approaches in fuel distribution contexts. To address these issues, this research proposes the implementation of the Hazard Identification, Risk Assessment, and Risk Control (*HIRARC*) method. *HIRARC* is a comprehensive approach to managing operational safety through systematic hazard identification, risk assessment, and the implementation of effective control measures. If these operational safety challenges are not addressed immediately, the escalating risk of accidents will not only result in increased financial losses exceeding IDR 5 billion annually but also pose significant threats of potential fatalities, severe environmental pollution from fuel spillage, and irreparable damage to corporate reputation, ultimately jeopardizing PT ABC's operational license and market position in the highly regulated fuel distribution industry. By applying this approach, the company is expected to minimize operational incidents, improve efficiency, and strengthen the internal enforcement of safety SOP[s].

This research aims to identify the key factors causing operational incidents at PT ABC, analyze risk levels and their probabilities, and provide data-driven recommendations for risk control and operational safety improvements. The study offers benefits at three distinct levels: theoretically, it contributes to the body of knowledge on integrated risk management methodologies by demonstrating the combined application of *HIRARC* and FTA in dynamic transportation environments, filling the gap in academic literature regarding fuel distribution safety management; practically, it provides PT ABC with evidence-based strategies for reducing operational incidents, improving cost efficiency, and ensuring regulatory compliance, while offering replicable frameworks for other fuel

distribution companies; and from a policy perspective, it supports regulatory bodies in developing industry-specific safety standards and guidelines that can be adopted across Indonesia's petroleum distribution sector, ultimately contributing to national workplace safety improvement initiatives. Through this research, PT ABC is expected to establish a safer and more sustainable safety management system.

RESEARCH METHOD

This research employs key theoretical frameworks to address operational truck accidents at PT. ABC in Jakarta, primarily utilizing the Hazard Identification, Risk Assessment, and Risk Control (*HIRARC*) method complemented by Fault Tree Analysis (FTA). Risk is fundamentally defined as a state of uncertainty involving the potential for losses or undesirable outcomes that can impact assets or the achievement of objectives, measured through its likelihood and severity. Specifically, operational risk refers to potential losses stemming from internal process failures, human error, system weaknesses, or external events. To manage this, the *HIRARC* process begins with hazard identification, which involves detecting sources of potential danger in the workplace.

The subsequent phase is risk assessment, which evaluates the significance of the identified hazards both qualitatively and quantitatively. This assessment utilizes standardized measurement scales for likelihood (from “Rare” to “Almost Certain”) and severity (from “Very Mild” to “Very Severe”) to calculate a risk level via a risk matrix. The matrix output, ranging from 1 to 25, categorizes risks as low, moderate, major, or high, determining the urgency and type of management response required. For a deeper analysis of system failures, the Fault Tree Analysis (FTA) method is applied; this is a deductive, probability-based approach that works backward from an undesired top event to systematically identify its root causes.

Once risks are assessed, the next critical step is risk control, which involves implementing measures to eliminate or reduce the identified risks. This is guided by the hierarchy of risk control, a systematic approach that prioritizes the most effective measures first. The hierarchy levels, in descending order of effectiveness, are: elimination, substitution, engineering controls, administrative controls, and finally, Personal Protective Equipment (PPE), which is considered the least effective and a last resort. This structured approach ensures hazards are managed in the most efficient way possible, whether by completely removing the hazard or protecting workers from it.

The practical application of these theories involves a structured research methodology. The study will be conducted over six months, focusing on data and incidents from July 2023 to June 2024 at the ABC Jakarta Branch. Data will be gathered through field studies and interviews with key personnel, including a Logistics Manager, QA, Fleet Management Head, a Mechanic, and seven drivers.

This collected data will then be processed using the *HIRARC* and FTA methods, following a flow that begins with hazard identification and proceeds through risk assessment, probability calculation, and finally, the implementation of appropriate risk controls.

RESULT AND DISCUSSION

Hazard Identification

In the process of hazard identification and risk assessment, each activity in fuel distribution is analyzed to measure the level of risk and its impact. The research findings reveal five main activities or factors identified as sources of potential hazards, with ten significant risks associated with fuel distribution operations. The outcomes of the hazard identification process are presented in the table below.

Table 1. Hazard Identification

Activity	Hazard Identification
Road Factors	Poor road conditions, including non-standard geometric design, high-speed limits, and inadequate lighting, contribute to higher accident rates (Chen et al., 2020; Duvvuri et al., 2022; Dong et al., 2015; Yan et al., 2009).
Vehicle Factors (Mechanical)	Issues such as brake system failure and improper maintenance are significant contributors to accidents (Waskito et al., 2024; Ghaleh et al., 2019).
Oil Leakage	Errors during oil loading and unloading can lead to spills and leaks, including overfilling tanks or improper handling of equipment (Crnčević, 2015).
	Lack of regular maintenance and inspection can cause undetected issues that eventually lead to leaks (Bongcales et al., 2024).
Tire Blowout	Tires not inflated to the recommended pressure can overheat due to increased friction, leading to blowouts (Li et al., 2010; In, 2008).
	Overinflation: Excessive air pressure can make tires too rigid, making them more susceptible to damage from road hazards (Li et al., 2010; Leng et al., 2008).
	Routine monitoring and maintenance of tire pressure and condition are crucial. Tires with cracks, aging, or structural damage are more prone to blowouts (Ratrout, 2005; Rudneva & Portola, 2023; Dolez et al., 2008).
	Lack of proper maintenance and inspection can cause undetected damage that may result in tire blowouts (Malakoutikhah et al., 2022; Ratrout, 2005).
Driver Factors	The main causes of truck accidents include violations such as speeding, failing to maintain lanes, and driving too fast (Rezapour & Ksaibati, 2018; Waskito et al., 2024; Munford, 2006).

Fatigue significantly increases the risk of accidents (Rezapour & Ksaibati, 2018; Benallou et al., 2023; Chen et al., 2020).

(Source: Literature Research)

Risk Assessment

Risk assessment is carried out to evaluate and examine the potential effects of hazards during fuel delivery operations. The objective is to assess the level of accident risk using two key factors: the likelihood of an incident occurring and the severity of its consequences.

Table 2. Frequency Level

Level	<i>Likelihood</i>	Description
5	<i>Almost Certain</i>	Occurs in almost all situations, for example, more than once a day.
4	<i>Likely</i>	Very likely to occur, for example, once a week.
3	<i>Probable</i>	Can occur occasionally, for example, once a month.
2	<i>Unlikely</i>	Might occur occasionally, for example, once in six months.
1	<i>Rare</i>	Only occurs in specific conditions, for example, once in more than six months.

Severity Category (Source: AS/NZS 4360)

Table 3. Severity Categories

	Severity Category	Parameter
1	Very Mild	No injuries, minimal financial loss, medical expenses < 100 thousand IDR.
2	Mild	Minor injuries requiring first aid, moderate material loss, medical expenses > 1 million IDR
3	Moderate	Requires medical attention, work stoppage, significant financial loss, medical expenses < 10 million IDR.
4	Severe	Loss of workdays, permanent/partial disability, moderate environmental damage, significant material loss, medical expenses < 50 million IDR.
5	Very Severe	Death, severe/permanent disability, severe environmental damage, significant material loss, medical expenses > 50 million IDR.

(Source: AS/NZS 4360)

Based on field findings, there were two tire blowout incidents, one accident due to driver fatigue, and one accident caused by technical brake system failure. The risk level calculations for these incidents are summarized in the following table:

Table 4. Risk Assessment

Potential Hazards	likelihood	Severity	Risk Level	Priority
Tire blowout	2	5	10	1
Driver fatigue	1	5	5	2
Brake system failure	1	5	5	3
Fuel leakage	0	5	0	4
Poor road conditions	0	5	0	5

(Source: Processed Data)

Fault Tree Analysis (FTA)

The FTA methodology provides systematic analysis of accident causation patterns, supported by empirical data from PT ABC operations. Ferdous et al. (2007) validated FTA effectiveness in complex system analysis, while László (2011) demonstrated its application in transportation risk assessment. Our FTA model incorporates both immediate causes and underlying organizational factors, consistent with contemporary risk analysis approaches that emphasize systemic rather than isolated failure modes. FTA uses quantitative methods to calculate the probability of a top event occurrence based on failure probabilities of basic events (Ferdous et al., 2007). In this case, FTA is used to identify and understand the top three priority hazards contributing to accidents.

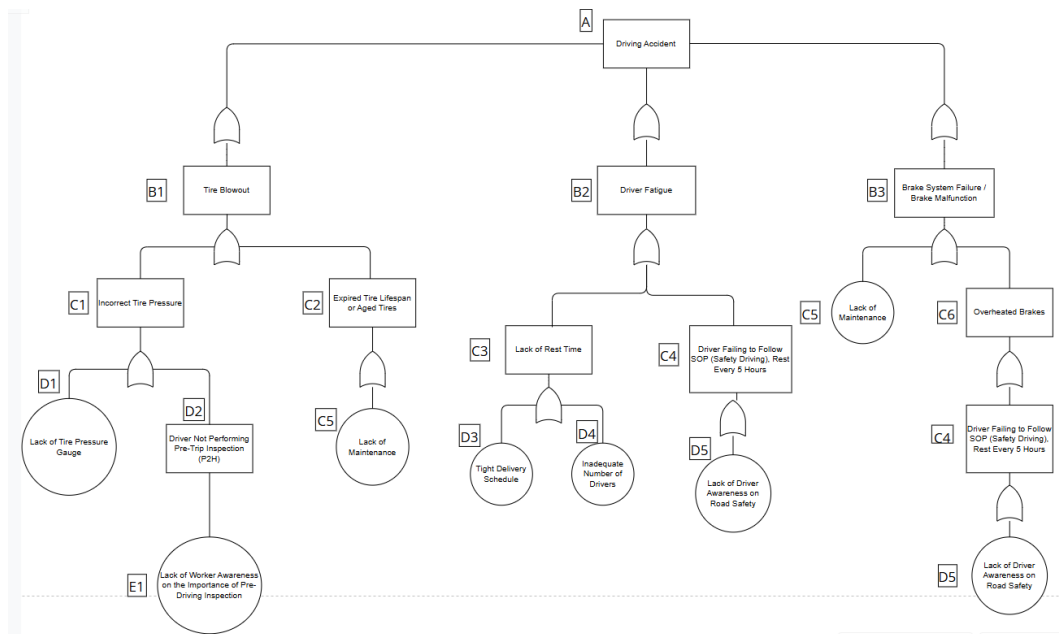


Figure 1. systematic analysis of accident causation patterns

Table 5. Fault Tree Analysis (FTA)

No	Notation	Description
1	A	Driving Accident
2	B1	Tire Blowout
3	B2	Driver Fatigue
4	B3	Brake System Failure / Brake Malfunction
5	C1	Incorrect Tire Pressure
6	C2	Expired Tire Lifespan or Aged Tires
7	C3	Lack of Rest Time
8	C4	Driver Failing to Follow SOP (Safety Driving), Rest Every 5 Hours
9	C5	Lack of Maintenance
10	C6	Overheated Brakes
11	D1	Lack of Tire Pressure Gauge
12	D2	Driver Not Performing Pre-Trip Inspection (P2H)
13	D3	Tight Delivery Schedule
14	D4	Inadequate Number of Drivers
15	D5	Lack of Driver Awareness on Road Safety
16	E1	Lack of Worker Awareness on the Importance of Pre-Driving Inspection

$$A = B1 + B2 + B3$$

$$A = ((C1 + C2) + (C3 + C4) + (C5 + C6))$$

$$A = ((D1 + D2) + (D3 + D4) + C6)$$

$$A = C5 \cdot D5 + C5 \cdot (D1 + D2) + C5 \cdot (D3 + D4)$$

$$A = C5 \cdot (D5 + (D1 + D2) + (D3 + D4))$$

$$A = C5 \cdot (D1 + D2 + D3 + D4 + D5)$$

$$A = C5 \cdot (D1 + D2 + D3 + D4 + D5)$$

From the above results, the main event (A) occurs if Lack of Maintenance (C5) happens along with any of D1, D2, D3, D4, or D5.

Probability Calculation :

Total Trips = 718

Total Incidents:

Tire Blowout = 2

Driver Fatigue = 1

Brake Failure = 1

Using the probability failure formula:

$$P_{\text{system}} = \text{Total Trips} / \text{Total Incidents}$$

next, using the system failure probability formula:

$$P_f = 1 - \prod_{i=1}^n (1 - P_i)$$

Table 6. description of probability failure formula

Incident	Number of Incidents	of Total Trips	Failure Probability (Pi)
Tire Burst (PB1)	2	718	2/718 = 0.00278
Driver Fatigue (PB2)	1	718	1/718 = 0.00139
Brake System Failure (PB3)	1	718	1/718 = 0.00139

- $P_{B1} = 0.00278$ (Tire Burst)
- $P_{B2} = 0.00139$ (Driver Fatigue)
- $P_{B3} = 0.00139$ (Brake System Failure)

Substituting the values:

$$P_f = 1 - (1 - 0.00278) \times (1 - 0.00139) \times (1 - 0.00139)$$

Calculating step by step:

$$1 - (0.99722 \times 0.99861 \times 0.99861)$$

$$1 - (0.99445)$$

$$P_f = 0.00556$$

Thus, the system failure probability is 0.56% or 0.00556 in decimal form.

Risk Control

Risk control in fuel distribution activities at PT. ABC is carried out to minimize potential hazards identified through the risk analysis process. Based on the research results, several risk control measures have been proposed to address identified issues such as tire blowouts, accidents due to driver fatigue, and brake system failures. These controls are based on the risk control hierarchy principles, including elimination, substitution, engineering controls, administrative controls, and the use of personal protective equipment (PPE).

The control measures include replacing vehicle tires that have reached their service life limit to reduce the risk of tire blowouts and adding a Tire Pressure Gauge to ensure tire pressure meets standards. Administrative controls involve tightening the Daily Inspection and Check Procedure (P2H), conducting regular

driver training on road safety, and implementing mandatory rest schedules to prevent driver fatigue. The risk control measures identified from the research are presented in the following table.

Table 7. Risk Control

Activity	Control Actions	Safety Implementation
Road and environmental factors that increase accident risk.	Ensuring roads have appropriate curves, gradients, and widths to accommodate traffic safely (Hong et al., 2010; Das et al., 2024).	1. Road Survey: Before delivery, inspect the route conditions, including road surface conditions, sharp turns, and poorly lit areas. 2. Avoiding Risky Routes: Plan alternative routes to avoid damaged, slippery, or accident-prone areas.
	Applying conspicuity treatments to trucks, such as reflective tape, can make them more visible at night, reducing collision risk (Sullivan & Flannagan, 2012)	3. Installing Adequate Lighting Equipment on truck units.
Mechanical Failure	Regular and thorough inspections of trucks to ensure good mechanical condition can prevent accidents (Blower et al., 2010; Yuan et al., 2019).	1. Establishing a Routine Breakdown Schedule to check brakes, undercarriage, and other vital vehicle components.
	Ensuring systematic inspection and maintenance of trucks to prevent mechanical failures (Ghaleh et al., 2019).	2. Implementing Predictive Maintenance based on historical data, real-time condition monitoring, and predictive analysis.
Oil Leakage	Routine maintenance and inspection of storage system integrity and pipelines are crucial (Nicotra et al., 2024).	1. Regular inspections of truck tanks and pipelines.
	Regular training programs for operators on leak detection, emergency response, and environmental management are essential. Enhancing personnel skills and awareness at the site can significantly improve leakage prevention and control (Lee & Othman, 2008).	2. Worker training on fuel handling. 3. Emergency equipment for leaks (Fire extinguisher & Absorbent materials).
	Flammable or toxic gas detectors are essential for early leak detection. These detectors should be strategically placed to optimize effectiveness, considering factors such as	4. Leak detection technology.

	distance from the leak point and ground level (Barbosa Alves et al., 2022).	
Tire Burst	Proper Maintenance: Regular inspection and maintenance of tires, including checking for cracks, wear, and proper pressure, are essential (Ratrou, 2005; Rudneva & Portola, 2023).	1. Daily Inspection and Check (P2H) before and after delivery activities. 2. Replacing old tires before failure. Tires should be replaced when their thickness reaches 4mm, which is 1mm above the recommendation from the Indonesian Ministry of Transportation (3mm).
	Implementing a Tire Pressure Monitoring System (TPMS) can assist in early detection of underinflation or overinflation issues (In, 2008).	3. Standardizing Tire Pressure Levels. 4. Using additional tools such as a Tire Pressure Gauge to ensure tire pressure meets the standard.
Driver Factors	Enhanced training programs focusing on safe driving practices and handling hazardous materials can reduce accidents (Reiman et al., 2018).	1. Providing training related to driving safety. 2. Enforcing a rest policy every four hours of driving.
	Implementing measures to manage driver fatigue, such as regulated driving hours and breaks, is essential (Benallou et al., 2023; Chen et al., 2020).	3. Conducting health check-ups (Medical Check-Up every six months) for drivers, performed at a company-designated clinic. 4. Checking temperature, blood pressure, and alcohol levels before delivery (assisted by an assigned supervisor).

The risk control measures implemented starting in July 2024 have proven effective in minimizing operational accidents within the company. This success has been achieved through stricter enforcement of the Daily Inspection and Check Procedure, monthly driver training sessions, and scheduled vehicle maintenance. As a result, incident rates have declined, reducing vehicle downtime and ensuring more punctual deliveries.

Table 8 below presents data on incidents and on-time delivery percentages from January 2024 to December 2024. After implementing the proposed measures based on the analysis, a gradual improvement was observed starting in July 2024, reaching 100% by the end of Q3 and maintaining this level throughout Q4 2024. The on-time delivery rate reflects the absence of road troubles during delivery operations.

Tabel 8. Percentage *On Time Delivery*

Month	Number of incidents	On-Time Delivery Percentage
January	0	95%
February	0	89%
March	0	92%
April	0	96%
May	1	90%
June	2	88%
July	0	95%
August	0	96%
September	0	100%
October	0	100%
November	0	100%
December	0	100%

(Source: ABC, 2024)

CONCLUSION

This research confirms that safety in fuel oil (*BBM*) distribution is strongly influenced by the effectiveness of risk control strategies. Based on analysis using *HIRARC* and Fault Tree Analysis (FTA) methods, it was found that the main factors causing incidents in fuel distribution operations at PT ABC include suboptimal vehicle maintenance, inappropriate tire pressure, driver fatigue, and brake system failure. The implementation of risk control measures, such as daily inspections (*P2H*), the use of tire pressure gauges, and safety training for drivers, proved effective in reducing the operational incident rate. The results show that the implementation of stricter safety procedures has a positive impact on improving the efficiency of fuel distribution, which is characterized by a decrease in the number of incidents and the achievement of 100% on-time delivery by the final quarter of 2024. In conclusion, adherence to standard operating procedures (SOPs), implementation of sustainable vehicle maintenance programs, and increased driver safety awareness are key factors in building a safer, more efficient, and sustainable fuel distribution system.

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