

Occupational and Operational Risk Assessment in Trans Jogja Public Transportation Using HIRADC and FTA

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ABSTRACT

Urban public transportation operations are exposed to a range of operational, technical, and human-factor risks that may lead to traffic accidents, occupational injuries, and service disruptions. However, previous transportation safety studies have rarely integrated workshop hazards, operational routes, and driver-related risks within a unified risk-management framework. Therefore, this study aims to develop an integrated operational risk-control framework for urban public transportation systems using the Hazard Identification, Risk Assessment, and Determining Control (HIRADC) and Fault Tree Analysis (FTA) methods. This study employed a mixed-method descriptive approach involving workshop activities, operational routes, and driver-related operational factors in Trans Jogja operations. Data were collected through observations, interviews, and questionnaires involving mechanics and drivers. The HIRADC analysis identified several high-risk activities related to workshop operations, traffic conditions, and driver performance, particularly welding activities, manual handling, congested intersections, aggressive road-user behavior, and driver fatigue. Furthermore, the FTA results revealed that accident risks were influenced by interactions among human, managerial, technical, and environmental factors. Recommended control measures include stricter implementation of standard operating procedures, defensive driving training, ergonomic improvements, optimization of driver work-rest schedules, and traffic engineering improvements. The findings demonstrate that safety risks in urban public transportation systems are multidimensional and interconnected across operational domains. This study contributes by integrating HIRADC-based risk assessment with FTA-based root cause analysis to support comprehensive transportation safety risk management.

Keywords: HIRADC, FTA, Risk Control, Trans Jogja, Transportation Safety.

Introduction

Public urban bus transportation is one of the essential components of urban mobility systems, as it plays a significant role in improving public accessibility, reducing private vehicle dependency, and minimizing traffic congestion [1]. The availability of safe and reliable public transportation has therefore become increasingly important in urban areas experiencing rapid motorized vehicle growth. However, the increasing complexity of urban traffic conditions has also heightened operational safety risks in public transportation systems [2]. Road infrastructure conditions, traffic density, vehicle conditions, road-user behavior, and human factors are among the major contributors to transportation accidents in urban environments [3]. In urban public transportation systems, safety risks are interconnected across operational, technical, and human factors, requiring integrated risk management rather than isolated safety assessments.

Trans Jogja, as one of the primary urban bus transportation systems in the Special Region of Yogyakarta, plays an important role in supporting urban mobility and reducing reliance on private vehicles [4]. As passenger demand and operational frequency continue to increase, Trans Jogja must maintain high standards of operational safety and service reliability [5]. Nevertheless, Trans Jogja operations involve various risks arising from operational routes, driver-related factors, and technical disruptions during fleet maintenance activities [2]. Unlike manufacturing systems, urban public transportation operations involve dynamic interactions among drivers, passengers, traffic conditions, infrastructure, and vehicle maintenance systems, creating safety challenges more complex than those typically found in manufacturing environments.

Transportation safety in the Special Region of Yogyakarta remains a significant concern due to increasing traffic complexity and accident trends [6]. Several transportation accident cases reported by

the National Transportation Safety Committee (KNKT) further highlight the importance of systematic risk control in urban bus operations such as Trans Jogja. One of the major contributors to transportation safety risks in urban bus operations is the condition of operational routes and surrounding traffic environments [7]. Operational route conditions, traffic density, and interactions with other road users are important factors influencing accident risks in urban bus transportation systems [8]. Increasing traffic congestion and rapid motor vehicle growth in Yogyakarta have intensified traffic complexity along the operational routes of Trans Jogja [9]. In addition, suboptimal road geometric conditions, including narrow roads, limited road shoulders, and insufficient warning signs, may increase collision risks and emergency maneuvers during bus operations [10]. These conditions demonstrate that operational risks in urban transportation systems are highly dynamic and influenced by interactions among infrastructure, traffic conditions, and driver responses.

Driver-related factors are also among the primary causes of accidents in urban bus transportation operations. Aggressive driving behavior, non-compliance with traffic regulations, limited situational awareness, and decreased alertness due to fatigue may significantly increase accident probability [11]. Continuous driving activities in congested urban environments expose drivers to high physical and mental workloads. Long and repetitive work shifts, traffic congestion, and monotonous driving conditions may reduce concentration and driving performance [12]. From a human factors perspective, driver fatigue and excessive workload directly affect cognitive performance, reaction time, and operational decision-making, thereby increasing operational safety risks. Operational accident records from Trans Jogja operations also indicate that accidents occur across multiple operational routes, suggesting that operational intensity and traffic exposure contribute significantly to transportation safety risks.

Safety risks in Trans Jogja operations are not limited to operational driving activities; they also occur during fleet maintenance in workshops. Workshop environments pose various occupational hazards, including the use of heavy equipment, exposure to chemicals, high-temperature work, and vehicle repair processes, which may lead to occupational injuries or technical vehicle failures [13]. The implementation of Occupational Health and Safety (OHS) practices at the Pool Purosani workshop also faces challenges, including inconsistent use of personal protective equipment (PPE), limited worker awareness of OHS procedures, and inconsistent adherence to standard operating procedures (SOPs) [14]. In addition, the imbalance between the number of mechanics and operational fleets may increase workloads, human error during maintenance activities, and the risk of vehicle failures during operation. These conditions indicate that workshop safety issues may indirectly influence operational transportation safety, highlighting the importance of integrating occupational and operational risk management within urban public transportation systems.

Several previous studies have examined hazard identification and risk analysis using the Hazard Identification, Risk Assessment, and Determining Control (HIRADC) and Fault Tree Analysis (FTA) methods. Previous studies demonstrated that HIRADC is effective for identifying high-risk work activities and determining appropriate control measures, while FTA is useful for analyzing root causes of occupational accidents [15],[16],[17]. However, existing studies have primarily focused on manufacturing industries and general workshop environments. Studies examining integrated safety risks in urban public transportation systems remain limited, particularly those involving operational routes, driver-related risks, and maintenance workshop activities within a unified risk-management framework. Furthermore, previous studies generally analyzed hazard identification and root causes separately, resulting in limited understanding of the interactions among operational, technical, and human-factor risks in urban bus transportation systems. Research integrating HIRADC and Fault Tree Analysis (FTA) for urban public transportation safety management also remains limited. Therefore, this study aims to identify potential hazards, assess risk levels, and analyze the root causes of accidents in Trans Jogja operations using the HIRADC and FTA methods. This study contributes to urban transportation safety research by integrating HIRADC-based operational risk assessment with FTA-based root cause analysis across driver, operational route, and fleet maintenance workshop domains to develop a comprehensive operational risk-control framework for urban public transportation systems.

Research Methods

Research Location and Subjects

This study was conducted at three main locations. The first location was the Trans Jogja Purosani Pool, located in Balecatu Residential Area, Gamping District, Sleman Regency, Special Region of Yogyakarta. The second location was Trans Jogja Route 10 on the Gamping–Kusumanegara corridor.

The third location was Trans Jogja Route 3B on the Giwangan–Condongcatur corridor. The selection of Route 10 and Route 3B was based on their highest accident frequencies. The sampling technique employed in this study was total sampling. Total sampling is a sampling technique in which the entire population serves as respondents [18]. The study population consisted of 20 workshop mechanics at Purosani Pool and 30 Trans Jogja drivers on Routes 10 and 3B. Therefore, the total sample size was 50 respondents.

Research Type and Data Collection Techniques

This study employed a descriptive research design using a mixed-methods approach that integrates qualitative and quantitative methods [19], [20]. The mixed-methods approach was selected because transportation safety risks involve operational, technical, and human-factor aspects that require both quantitative risk assessment and qualitative analysis. The quantitative approach was used to assess risk levels using likelihood and severity scales based on ISO 45001:2018 standards [21]. Meanwhile, the qualitative approach was applied for hazard identification, root cause analysis, and determination of risk control measures. Data collection was conducted through observations, semi-structured interviews, questionnaires, and documentation studies. Observations were conducted in workshop areas and along operational routes, while interviews were conducted with mechanics, drivers, and operational supervisors. Secondary data included accident records, operational reports, occupational safety regulations, and relevant literature obtained from PT Anindya Mitra Internasional [22], [23]. The overall research procedure consisted of problem identification, literature review, data collection, hazard identification using HIRADC, risk assessment, determination of risk control measures, and root cause analysis using FTA. The research flow is presented in Figure 1.

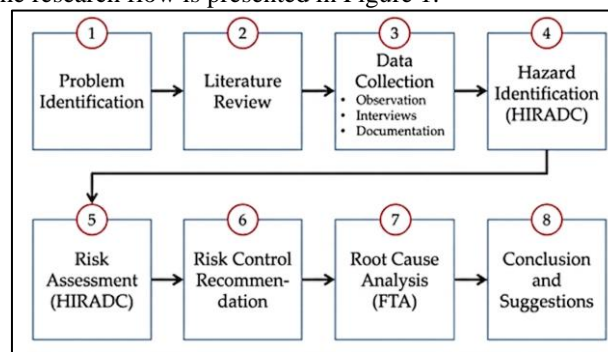


Figure 1. Research flow diagram

Data Analysis Techniques

This study utilized two primary instruments, namely Hazard Identification, Risk Assessment and Determining Control (HIRADC) and Fault Tree Analysis (FTA). The HIRADC method was employed to identify potential hazards, assess risk levels, and determine appropriate risk control measures in Trans Jogja operations. The method was selected because it provides a systematic framework for managing occupational and operational risks in transportation systems. Risk assessment was conducted using likelihood and severity scales ranging from 1 to 5, in accordance with ISO 45001:2018. The determination of likelihood and severity scores was conducted through expert judgment involving operational supervisors, mechanics, and experienced drivers. The scoring results were validated through discussions with operational personnel to ensure consistency in the risk assessment process. The likelihood and severity risk matrix used in this study is presented in Table 1.

Table 1. Risk matrix based on likelihood and severity

| Likelihood | | Severity | | | | |
|------------|----------------|------------|-------|----------|-------|--------|
| | | 1 | 2 | 3 | 4 | 5 |
| | | Negligible | Minor | Moderate | Major | Severe |
| 1 | Rare | 1 | 2 | 3 | 4 | 5 |
| 2 | Unlikely | 2 | 4 | 6 | 8 | 10 |
| 3 | Possible | 3 | 6 | 9 | 12 | 15 |
| 4 | Likely | 4 | 8 | 12 | 16 | 20 |
| 5 | Almost Certain | 5 | 10 | 15 | 20 | 25 |

Source: ISO 45001:2018

Risk values were calculated using the Risk Rating (RR) equation:

$$RR = \text{Likelihood} \times \text{Severity} \tag{1}$$

Where RR = Risk Rating, L = Likelihood, and S = Severity. The calculated risk values were subsequently classified into low, medium, high, and extreme risk categories. The risk classification used in this study is presented in Table 2.

Table 2. Risk level classification

| Risk Category | Score Range | Description |
|-------------------|-------------|--|
| Low Risk (LR) | 1-4 | Risk control is carried out using existing procedures by the relevant parties |
| Medium Risk (MR) | 5-9 | Preventive measures are required to avoid incidents |
| High Risk (HR) | 10-16 | Immediate and concrete action from management is required to prevent accidents |
| Extreme Risk (ER) | 20-25 | Ongoing activities must be stopped immediately |

Source: ISO 45001:2018

The next stage involved determining risk control measures based on the hierarchy of controls, including elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE). Furthermore, Fault Tree Analysis (FTA) was applied to analyze the root causes of dominant risks identified from the HIRADC assessment results. Top events in the FTA analysis were selected based on the highest risk scores identified in each operational domain. The FTA process was conducted using a top-down approach through AND and OR logic gates. The fault tree structures were validated through discussions with operational supervisors and personnel.

Results and Discussion

Risk Assessment and Control in the Trans Jogja Workshop Pool Purosani

The results of the risk assessment for the Pool Purosani workshop area indicated that most work activities were classified as medium- to high-risk. High-risk activities were identified in underbody repair, welding operations, manual material handling, and jack utilization due to exposure to hazardous equipment, confined workspaces, and non-ergonomic working conditions. Meanwhile, workshop dust exposure and oil spills were classified as low risks. The detailed risk assessment results are presented in Table 3.

Table 3. Risk assessment results in the Pool Purosani Trans Jogja workshop area

| No | Work Activity | Hazard | Risk Impact | Risk Assessment | | | Level |
|----|-------------------------------|--|---|-----------------|---|----|-------|
| | | | | LI | S | RR | |
| 1 | Vehicle electrical inspection | Electric shock | Shock sensation, numbness, muscle pain, and cramps | 3 | 2 | 6 | MR |
| 2 | Fan belt inspection | Hand slipping during inspection | Scratches or abrasions caused by contact with engine components | 4 | 2 | 8 | MR |
| 3 | Vehicle washing | Slippery floor (slip/fall hazard) | Temporary shock and muscle stiffness in muscles or tailbone | 3 | 2 | 6 | MR |
| 4 | Battery water filling | Skin contact with battery fluid | Burning sensation, pain, and skin redness | 2 | 3 | 6 | MR |
| 5 | Air filter replacement | Exposure to dust and combustion residue smoke | Temporary respiratory disturbance | 3 | 2 | 6 | MR |
| 6 | Understell repair | Collision with vehicle frame or underbody components | Bruises, swelling, abrasions, body pain, and temporary dizziness | 4 | 3 | 12 | HR |
| 7 | Welding activity | Direct exposure to ultraviolet welding rays | Minor burns, respiratory disorders, eye irritation, and temporary visual impairment | 4 | 3 | 12 | HR |
| 8 | Vehicle roof repair | Slippery bus roof surface (fall hazard) | Serious injury such as bone fractures | 2 | 4 | 8 | MR |
| 9 | Cooling system maintenance | Inhalation of leaked refrigerant gas | Mild temporary respiratory disturbance | 3 | 2 | 6 | MR |
| 10 | Engine oil replacement | Contact with oil | Burning sensation, redness, and itching on the skin | 3 | 3 | 9 | MR |
| 11 | Tire replacement | Tire falling during wheel hub removal | Finger or foot injuries caused by falling tires | 3 | 3 | 9 | MR |

| | | | | | | | |
|----|---|---|---|---|---|----|----|
| 12 | Lifting and moving heavy loads (<i>manual handling</i>) | Excessive load and non-ergonomic posture | Back injuries and muscle fatigue | 4 | 3 | 12 | HR |
| 13 | Jack utilization | Crushed or trapped by vehicle | Serious injury | 2 | 5 | 10 | HR |
| 14 | Workshop dust exposure | Dust particles inhaled by mechanics | Respiratory and visual disturbances | 2 | 2 | 4 | LR |
| 15 | Oil spill | Slippery workshop floor (<i>slipping/falling</i>) | Feeling startled and temporary muscle stiffness | 2 | 2 | 4 | LR |

The results indicate that the workshop domain contained several high-risk activities, particularly underbody repair, welding, manual handling, and jack utilization. These risks were mainly influenced by direct exposure to hazardous equipment, confined workspaces, and non-ergonomic working conditions. Based on these findings, risk control efforts focused on engineering controls, administrative controls, and the use of personal protective equipment (PPE). The detailed recommendations for risk control measures are presented in Table 4.

Table 4. Determining control measures in the Trans Jogja workshop area

| No | Hazard | Level | Control Measures |
|----|--|-------|---|
| 1 | Electric shock | MR | <ul style="list-style-type: none"> Engineering Control: Ensuring the vehicle is turned off and disconnecting the negative terminal. PPE: Using insulated electrical gloves and safety shoes. |
| 2 | Hand slipping during inspection | MR | <ul style="list-style-type: none"> Engineering Control: Ensuring the fan belt cover is properly installed and using inspection aids such as work flashlights or inspection mirrors, especially in low-light engine areas. PPE: Using mechanic gloves and safety shoes. |
| 3 | Slippery floor (slip/fall hazard) | MR | <ul style="list-style-type: none"> Engineering Control: Conducting routine housekeeping after vehicle washing activities. Administrative Control: Separating the vehicle washing area from the main work area. PPE: Using anti-slip safety shoes and work gloves. |
| 4 | Skin contact with battery fluid | MR | <ul style="list-style-type: none"> Engineering Control: Ensuring the vehicle electrical system is inactive. PPE: Using special gloves, safety goggles, masks, and wearpacks. |
| 5 | Exposure to dust and combustion residue smoke | MR | <ul style="list-style-type: none"> Engineering Control: Performing cleaning activities in well-ventilated areas and removing dirt from air filters in the work area. PPE: Using gloves, masks, and safety goggles. |
| 6 | Collision with vehicle frame or underbody components | HR | <ul style="list-style-type: none"> Engineering Control: Using a permanent inspection pit during underbody inspection and using jack stands on vehicle wheels. Administrative Control: Conducting safety briefings before work and implementing SOPs. PPE: Using safety goggles, gloves, safety shoes, and wearpacks. |
| 7 | Direct exposure to ultraviolet welding rays | HR | <ul style="list-style-type: none"> Administrative Control: Implementing welding SOPs and conducting regular inspections of welding equipment. PPE: Using welding helmets, heat-resistant welding gloves, safety shoes, and wearpacks. |
| 8 | Slippery bus roof surface (fall hazard) | MR | <ul style="list-style-type: none"> Engineering Control: Avoiding work when the roof surface is wet or slippery and using portable scaffolding to prevent falls from height. PPE: Using safety harnesses, safety helmets, and anti-slip safety shoes. |
| 9 | Inhalation of leaked refrigerant gas | MR | <ul style="list-style-type: none"> Substitution: Using refrigerants with lower toxicity levels. PPE: Using respirator masks, mechanic gloves, and safety goggles. |
| 10 | Contact with oil | MR | <ul style="list-style-type: none"> Engineering Control: Avoiding work while the engine temperature is still hot. PPE: Using oil/chemical-resistant mechanic gloves and safety shoes to avoid exposure to contaminated used oil. |
| 11 | Tire falling during wheel hub removal | MR | <ul style="list-style-type: none"> Engineering Control: Using wheel stoppers and wheel removal tools, and ensuring the work surface is stable. PPE: Using safety shoes and gloves to prevent slipping while lifting tires. |
| 12 | Excessive load and non- | HR | <ul style="list-style-type: none"> Substitution: Using supporting equipment such as trolleys, pallet jacks, or forklifts to avoid manual lifting. |

| | | | |
|----|--|----|---|
| | ergonomic posture | | <ul style="list-style-type: none"> • Engineering Control: Arranging storage room layouts and using ergonomically designed storage racks. • Administrative Control: Educating mechanics on proper and safe manual handling techniques and reducing lifting frequency. • PPE: Using wearpacks, safety shoes, gloves, and back support belts. • Substitution: Using permanent hydraulic vehicle lifts instead of manual jacks. |
| 13 | Crushed or trapped by vehicle | HR | <ul style="list-style-type: none"> • Engineering Control: Ensuring lifting points comply with standards and the floor surface is stable and level. • Administrative Control: Implementing Jack Usage SOPs. • PPE: Using wearpacks and safety shoes. |
| 14 | Dust particles inhaled by mechanics | LR | <ul style="list-style-type: none"> • Engineering Control: Installing ventilation systems and exhaust fans to improve workshop air circulation. • Administrative Control: Implementing routine housekeeping schedules. • PPE: Using masks and safety goggles. |
| 15 | Slippery workshop floor (slipping/falling) | LR | <ul style="list-style-type: none"> • Engineering Control: Routinely cleaning the workshop area. • Administrative Control: Providing used oil waste storage containers (hazardous waste/B3 waste). • PPE: Using safety shoes and mechanic gloves. |

Risk Assessment on Trans Jogja Routes 3B and 10

The risk assessment results on Trans Jogja operational routes indicated that aggressive behavior of other road users and congested intersections were categorized as high risks due to their potential to cause traffic accidents and fleet damage. Heavy traffic, potholes, illegal parking, and narrow roads were classified as medium risks, while road maintenance activities were categorized as low risks. The detailed results are presented in Table 5.

Table 5. Risk assessment results on Trans Jogja routes 3b and 10

| No | Work Activity | Hazard | Risk Impact | Risk Assessment | | | Level |
|----|--|------------------------------------|---|-----------------|---|----|-------|
| | | | | LI | S | RR | |
| 1 | Heavy traffic | Vehicle distance is too close | Traffic accidents causing injuries and fleet damage | 3 | 3 | 9 | MR |
| 2 | Congested intersections | Vehicles cutting into the bus lane | Traffic accidents causing injuries and fleet damage | 4 | 3 | 12 | HR |
| 3 | Potholes and uneven roads | Side conflicts with other vehicles | Vehicle suspension damage and traffic accidents causing injuries and fleet damage | 2 | 3 | 6 | MR |
| 4 | Road maintenance | Narrowing of bus operational lanes | Minor collision with other vehicles (bus body scratches) | 2 | 2 | 4 | LR |
| 5 | Illegal parking | Obstructing bus movement | Traffic accidents causing injuries and fleet damage | 3 | 3 | 9 | MR |
| 6 | Wet roads and water puddles | Bus skidding and loss of control | Bus colliding with fixed objects and sustaining damage | 2 | 3 | 6 | MR |
| 7 | Tree branches extending into the roadway | Branches striking the vehicle | Vehicle damage and scratches | 3 | 2 | 6 | MR |
| 8 | Narrow two-way roads | Limited bus maneuvering space | Side collision with other vehicles | 3 | 2 | 6 | MR |
| 9 | Aggressive behavior of other drivers | Reckless driving by other vehicles | Traffic accidents causing injuries and fleet damage | 5 | 3 | 15 | HR |

The findings show that aggressive behavior of other road users and congested intersections were the dominant operational risks. Dense urban traffic conditions and unpredictable vehicle movements increased the likelihood of vehicle conflicts during bus operations. Therefore, risk control efforts focused on defensive driving training, vehicle speed management, and improved monitoring of operational route conditions. The detailed recommendations are presented in Table 6.

Table 6. Determining control measures on Trans Jogja routes 3b and 10

| No | Hazard | Level | Control Measures |
|----|------------------------------------|-------|--|
| 1 | Vehicle distance is too close | MR | <ul style="list-style-type: none"> • Engineering Control: Optimizing traffic management and maintaining safe following distances between vehicles during operations. • PPE: Use of seat belts. |
| 2 | Vehicles cutting into the bus lane | HR | <ul style="list-style-type: none"> • Engineering Control: Reducing speed and maintaining safe distances from other vehicles. • Administrative Control: Providing defensive driving training to drivers to anticipate hazards and avoid accident risks. |

| | | | |
|---|------------------------------------|----|---|
| 3 | Side conflicts with other vehicles | MR | <ul style="list-style-type: none"> • PPE: Use of seat belts. • Engineering Control: Installing bus-priority traffic signals and dedicated bus stop line markings. |
| 4 | Narrowing of bus operational lanes | LR | <ul style="list-style-type: none"> • PPE: Use of seat belts. • Elimination: Conducting permanent repairs on damaged road surfaces. • Administrative Control: Routine reporting to the relevant authorities for prompt repair handling. |
| 5 | Obstructing bus movement | MR | <ul style="list-style-type: none"> • Substitution: Temporary diversion of operational routes in roadwork segments. • Engineering Control: Installing clearly visible warning signs before damaged road sections. |
| 6 | Bus skidding and loss of control | MR | <ul style="list-style-type: none"> • Elimination: Enforcing restrictions on illegal parking along bus operational corridors. • Engineering Control: Installing no-parking signs and road shoulder stopping prohibition markings. |
| 7 | Branches striking the vehicle | MR | <ul style="list-style-type: none"> • Elimination: Improving road drainage systems in flood-prone segments. • Engineering Control: Reducing speed on wet and flooded roads. • PPE: Use of seat belts. |
| 8 | Limited bus maneuvering space | MR | <ul style="list-style-type: none"> • Elimination: Trimming tree branches that intrude into the vehicle clearance space along bus operational corridors. • Engineering Control: Installing warning signs for potential falling trees. |
| 9 | Reckless driving by other vehicles | HR | <ul style="list-style-type: none"> • Engineering Control: Reducing speed and maintaining safe distances from other vehicles. • Administrative Control: Installing safe-distance reminder stickers on the rear of buses. |

Driver Risk Assessment in Trans Jogja Operations

The driver risk assessment showed that driver fatigue was categorized as a high-risk indicator because it may reduce concentration and reaction capability during operations. Other indicators, including blind spot limitations and unsafe following distances, were categorized as medium risks, while failure to conduct pre-trip inspections was classified as a low risk. The detailed results are presented in Table 7.

Table 7. Driver risk assessment results in Trans Jogja operations

| No | Work Activity | Hazard | Risk Impact | Risk Assessment | | | Level |
|----|---|--|---|-----------------|---|----|-------|
| | | | | LI | S | RR | |
| 1 | Driver fatigue | Loss of driver concentration | Traffic accidents causing injuries and fleet damage | 4 | 3 | 12 | HR |
| 2 | Bus operation near bus stops | Bus positioned too close to the platform | Bus body collision with the bus stop and impact from other vehicles | 3 | 3 | 9 | MR |
| 3 | Insufficient anticipation of blind spots | Limited visibility on the left, right, and rear sides of the vehicle | Side collision or impact from other vehicles | 3 | 3 | 9 | MR |
| 4 | Failure to conduct pre-trip inspections | Minor vehicle damage during operations | Operational disruptions and service delays | 2 | 2 | 4 | LR |
| 5 | Failure to maintain safe following distance | Distance from other vehicles is too close | Side collision or impact from other vehicles | 3 | 3 | 9 | MR |

Driver fatigue emerged as the most critical driver-related risk due to prolonged driving activities and traffic congestion, which may reduce concentration and reaction capability during operations. Therefore, the proposed control measures focused on fatigue management, work-rest scheduling, defensive driving training, and the utilization of vehicle safety-support technologies. The detailed recommendations are presented in Table 8.

Table 8. Determining control measures in Trans Jogja operations

| No | Hazard | Category | Control Measures |
|----|------------------------------|----------|--|
| 1 | Loss of driver concentration | HR | <ul style="list-style-type: none"> • Engineering Control: Installing drowsiness detection systems, adjusting driver seat ergonomics, and regulating cabin temperature to reduce physical fatigue. |

| | | | |
|---|--|----|---|
| 2 | Bus positioned too close to the platform | MR | <ul style="list-style-type: none"> Administrative Control: Regulating working hours and rest periods, implementing fatigue management training, and conducting routine health examinations. PPE: Use of seat belts and sunglasses to reduce eye fatigue caused by sunlight glare. Elimination: Reducing vehicle speed when approaching bus stops. Engineering Control: Applying clear yellow/white road markings to guide drivers in aligning buses with the platform and optimizing rear/side cameras to maintain safe distances from bus stops. |
| 3 | Limited visibility on the left, right, and rear sides of the vehicle | MR | <ul style="list-style-type: none"> PPE: Use of seat belts. Substitution: Installing additional cameras on the left, right, and rear sides of the bus to assist drivers in detecting objects outside their field of vision. |
| 4 | Minor vehicle damage during operations | LR | <ul style="list-style-type: none"> Engineering Control: Installing Blind Spot Alert stickers on the rear and sides of buses to warn other road users. Engineering Control: Prohibiting vehicle operation before pre-trip inspections are completed. |
| 5 | Distance from other vehicles is too close | MR | <ul style="list-style-type: none"> Administrative Control: Implementing pre-trip inspection SOPs and supervising vehicle inspections before operations. Engineering Control: Optimizing sensor systems that provide early warnings when the distance from the vehicle ahead is too close. Administrative Control: Conducting defensive driving training related to maintaining safe distances and hazard anticipation. PPE: Use of seat belts. |

Root Cause Analysis Using Fault Tree Analysis (FTA)

Based on the risk assessment using the HIRADC method, several hazard indicators with varying risk levels were identified across the workshop, operational route, and driver domains, as shown in Figure 2. Figure 2(a) shows that the workshop domain had the highest number of high-risk indicators, followed by the operational route and driver domains, indicating that vehicle maintenance and repair activities involve greater exposure to hazardous equipment, manual handling, and confined working areas, which require stricter risk control measures. Meanwhile, the operational route and driver domains also demonstrated significant safety risks associated with traffic density, aggressive road-user behavior, and driver fatigue during operations. Furthermore, Figure 2(b) illustrates the distribution of recommended control measures by control hierarchy, with engineering controls most dominant, followed by PPE and administrative controls. This finding indicates that operational safety improvements in Trans Jogja primarily depend on technical safety interventions, infrastructure improvements, and supporting administrative procedures, while elimination and substitution controls were less frequently applied due to the dynamic characteristics of urban transportation systems, which prevent certain risks from being completely eliminated.

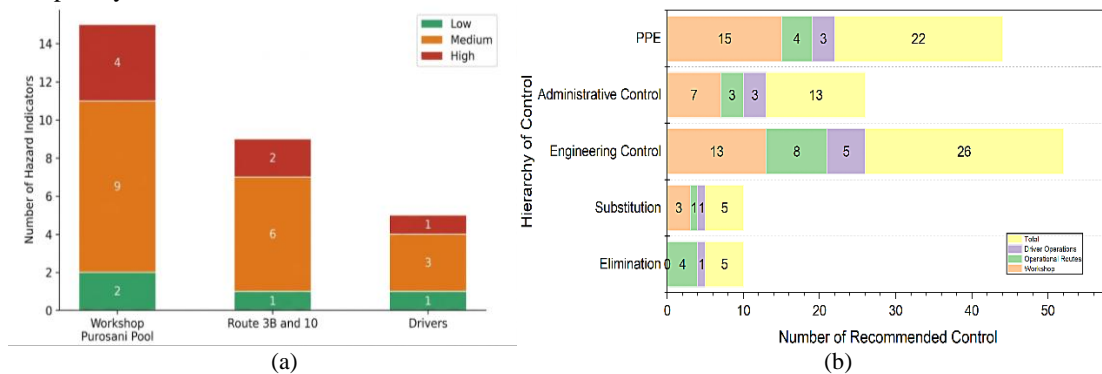


Figure 2. (a) Comparison of risk levels in operational, workshop, and drivers domains, (b) Distribution of recommended control measures based on the hierarchy of controls

Furthermore, the highest risk indicator from each variable was prioritized for further analysis using the Fault Tree Analysis (FTA) method. The list of selected risk indicators analyzed using FTA is presented in Table 9.

Table 9. High-risk indicators selected for Fault Tree Analysis (FTA)

| No | Work Activity | Risk Assessment | | | Level |
|----|--------------------------------------|-----------------|---|----|-------|
| | | LI | S | RR | |
| 1 | Aggressive Behavior of Other Drivers | 5 | 3 | 15 | HR |
| 2 | Underbody Repair Activities | 4 | 3 | 12 | HR |

The FTA results showed that aggressive road-user behavior was influenced by unsafe driving practices and traffic congestion. Underbody repair risks were associated with inadequate engineering controls and unsafe work behavior, while driver fatigue was influenced by insufficient rest periods and demanding operational conditions. These findings demonstrate that operational safety risks are affected by interactions among human, managerial, and environmental factors. Through this analysis, the dominant causes of operational and workplace accidents can be identified to support more effective, targeted risk-control measures.

1. Fault Tree Analysis of Aggressive Behavior of Other Drivers

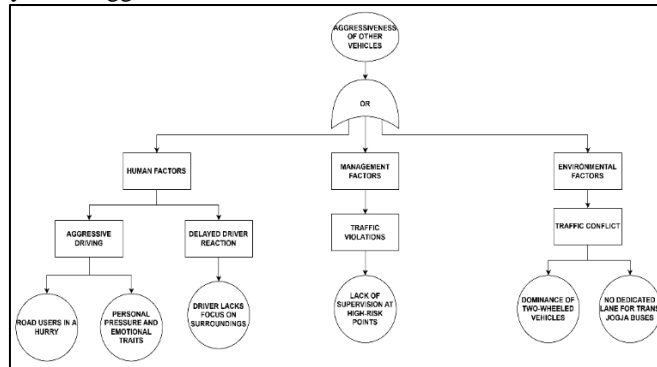


Figure 3. Fault tree analysis of the aggressive behavior of other drivers

The FTA results indicate that accident risks were influenced by unsafe driving behaviors from surrounding road users, including sudden lane changes, speeding, and reckless overtaking. Dense urban traffic conditions and limited traffic control systems further intensified interactions between buses and private vehicles, thereby increasing the potential for vehicle conflicts during operations. These findings suggest that aggressive road-user behavior represents a significant external risk factor in urban public transportation systems.

2. Fault Tree Analysis of Underbody Repair Activities

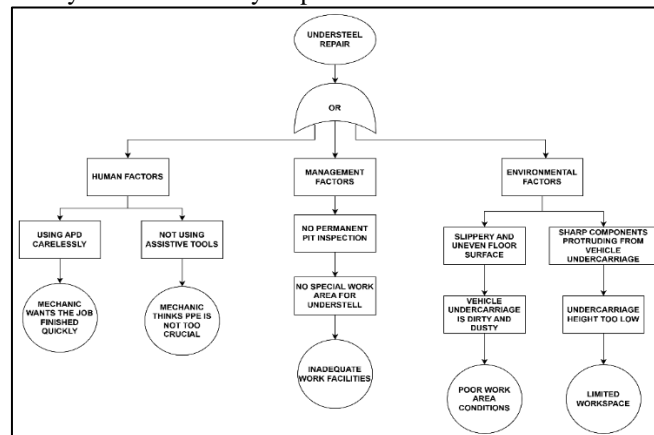


Figure 4. Fault tree analysis of underbody repair activities

The FTA results indicate that underbody repair risks were influenced by unsafe work behavior, inadequate PPE compliance, and limited engineering safety controls, particularly the absence of permanent inspection pits. In addition, confined workspaces and non-ergonomic postures increased the risk of crush injuries and musculoskeletal disorders during maintenance activities. These findings demonstrate that workshop accident risks are associated not only with worker behavior but also with limitations in workshop infrastructure and safety management systems.

3. Fault Tree Analysis of Driver Fatigue

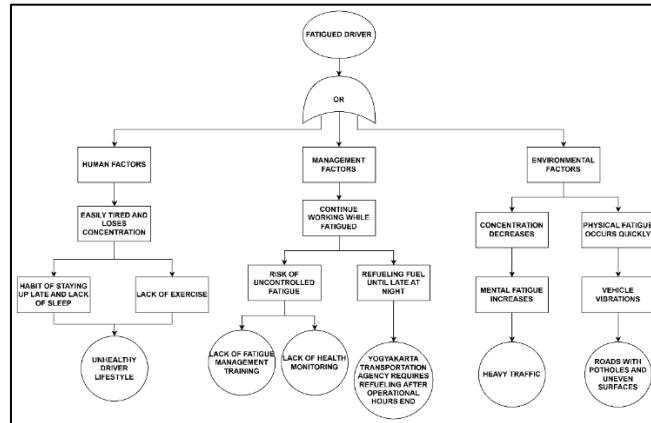


Figure 5. Fault Tree Analysis of Driver Fatigue

The FTA results indicate that driver fatigue was influenced by insufficient rest periods, prolonged driving activities, traffic congestion, and demanding operational conditions. These factors may reduce concentration, alertness, and reaction capability during bus operations. From a human factors perspective, excessive workload and repetitive driving activities may negatively affect driver performance and increase the likelihood of traffic accidents. Therefore, fatigue management should become a priority component of operational safety management in urban public transportation systems.

Conclusion

This study successfully identified and analyzed occupational and operational risks within three operational domains of Trans Jogja using the Hazard Identification, Risk Assessment, and Determining Control (HIRADC) and Fault Tree Analysis (FTA) methods. The results identified several risk indicators, ranging from low to high, across workshop activities, operational routes, and driver operations. The workshop domain showed the highest number of high-risk indicators, particularly in underbody repair activities, welding activities, manual handling, and jack utilization. In the operational route domain, aggressive behavior of other drivers (RR = 15) became the highest risk indicator, while driver fatigue (RR = 12) was identified as the dominant risk factor in the driver domain. Based on the risk assessment results, the highest risk indicator from each operational variable was further analyzed using the FTA method, namely aggressive behavior of other drivers, underbody repair activities, and driver fatigue. The FTA analysis demonstrated that accident risks in Trans Jogja operations are multidimensional and arise from the interaction of human, managerial, and environmental factors. Unsafe work behavior, inadequate safety facilities, weak implementation of safety procedures, high operational workloads, and dense urban traffic conditions were identified as the dominant contributing factors to accidents and operational disruptions. Therefore, effective risk mitigation requires an integrated approach involving stricter implementation of standard operating procedures (SOPs) and personal protective equipment (PPE) usage, ergonomic improvements in workshop activities, enhancement of traffic management systems, defensive driving training, fatigue management programs, and the utilization of safety-supporting technologies such as drowsiness detection systems and dashboard cameras. Furthermore, integrating HIRADC and FTA methods proved effective in identifying the root causes of hazards and generating more comprehensive, targeted risk control recommendations to improve occupational and operational safety performance in urban public transportation systems.

References

- [1] D. Pramesti, N. L. P. J. A. Andini, D. A. K. R. Raharjo, and A. D. Dwipayana, "Efektivitas Penggunaan Moda Transportasi Umum Dengan Kendaraan Pribadi," *Indonesian Journal of Multidisciplinary on Social and Technology*, vol. 2, no. 1, pp. 6–16, Jan. 2024, doi: 10.31004/ijmst.v2i1.246.
- [2] M. N. Wahid, F. D. R. Prayudhi, C. D. Mayatika, and B. Mardikawati, "Analisis Kinerja Layanan Pada Bus (Tmd) Trans Metro Dewata Bali: (Studi Kasus Pada Koridor 3b Terminal

- Ubung-Matahari Terbit Sanur),” vol. 25, no. 1, pp. 45–56, 2025, doi: 10.26593/jtrans.v25i1.9405.45-56.
- [3] N. Fitriani *et al.*, “Pengaruh Kondisi Infrastruktur Lingkungan Jalan Terhadap Keselamatan Lalu Lintas Angkutan Jalan: Systematic Review,” *Jurnal Teknik Sipil Dan Arsitektur*, vol. 30, no. 2, p. 150, 2025, doi: 10.36728/jtsa.v30i2.5192.
- [4] M. K. Devi, A. Y. E. Pramana, and R. Safitri, “Studi Komparatif Performa Angkutan BRT Transjogja dan Transjakarta,” *Jurnal Pengembangan Kota*, vol. 10, no. 1, pp. 93–103, Jul. 2022, doi: 10.14710/jpk.10.1.93-103.
- [5] Muryanti, C. Widodo, H. Mukaromah, and E. Putri, “Rasionalitas Pengguna Layanan Bus Rapid Transit (BRT) Transjakarta, Batik Trans Solo, dan Transjogja Pada Pilihan Transportasi Publik,” *Jurnal Perkotaan*, vol. 17, no. 1, pp. 12–24, Oct. 2025, doi: 10.25170/perkotaan.v17i1.6663.
- [6] T. Handoko, “Jumlah Kecelakaan di DIY Terus Naik, Kerugian Tertinggi Rp3,9 Miliar, Ini Detailnya,” *Harian Jogja*.
- [7] KNKT, “Kecelakaan Tunggal Mobil Bus Wisata Ad 1507 EH Tabrak Samping Bukit Bego, Karang Kulon, Wukirsari, Kec. Imogiri, Kabupaten Bantul, Daerah Istimewa Yogyakarta 6 Februari 2022.,” 2022.
- [8] Pandangan Jogja, “Rata-Rata Kecepatan Berkendara Orang Yogya Ternyata Tak Sampai 40 Km/Jam,” 2023. Accessed: May 18, 2026. [Online]. Available: <https://kumparan.com/pandangan-jogja/rata-rata-kecepatan-berkendara-orang-yogya-ternyata-tak-sampai-40-km-jam-212xZ77H2kX/full>
- [9] C. D. Janati, “Angka Kecelakaan Lalu Lintas DIY Diklaim Turun 4 Persen,” *Harian Jogja*, 2025. Accessed: May 17, 2026. [Online]. Available: <https://jogjapolitan.harianjogja.com/r-1230903/angka-kecelakaan-lalu-lintas-diy-diklaim-turun-4-persen>
- [10] P. Romadhona and A. Saputro, “Evaluasi Geometri Pada Tikungan Black Spot (Studi Kasus Jalan Parangtritis Km 15 Desa Patalan Kecamatan Jetis Kabupaten Bantul),” *Jurnal Teknik Sipil*, vol. 26, no. 3, pp. 249–256, Dec. 2019, doi: 10.5614/jts.2019.26.3.8.
- [11] D. Noviyanti and A. Munawar, “Perilaku Berkendara Pengemudi Trans Jogja dengan Menggunakan Tachometer,” *Jurnal Transportasi*, vol. 15, no. 1, pp. 41–50, 2015, doi: 10.26593/jtrans.v15i1.1849.%25p.
- [12] H. A. R. Hanani and N. D. P. Budiono, “Hubungan Faktor Individu dengan Kejadian Kecelakaan Kerja Pada Supir Bus,” *J-KESMAS: Jurnal Kesehatan Masyarakat*, vol. 11, no. 1, p. 69, May 2025, doi: 10.35329/jkesmas.v11i1.5997.
- [13] A. A. Dani, A. Octavianie, and F. Sabur, “Analisis Safety Risk Management di Workshop B AMTO 147D-13,” *JAMETS: Journal of Aircraft Maintenance Engineering & Aviation Technologies*, vol. 2, no. 1, pp. 1–11, Jun. 2023, doi: 10.46509/jamets.v2i01.437.
- [14] Wasiyem, D. R. Anggraini, and N. D. S. Panjaitan, “Analisis Keselamatan dan Kesehatan Kerja di Bengkel Mekanik dan Laboratorium,” *Jurnal Profesi Kesehatan Masyarakat*, no. 1, pp. 1–8, 2025, doi: 10.47575/jpkm.v6i1.676.
- [15] H. Pardede, T. Sukwika, and S. Sugiarto, “Analisis manajemen risiko penggunaan B3 dengan HIRADC pada proses produksi sizing agent,” *Jurnal Ilmu Kesehatan Bhakti Husada: Health Sciences Journal*, vol. 16, no. 01, pp. 206–215, Aug. 2025, doi: 10.34305/jikbh.v16i01.1577.
- [16] F. Apriliani, J. A. Zulkhulaifah, D. L. Aisara, F. R. Habibie, M. Iqbal, and S. A. Sonjaya, “Analisis Potensi Bahaya dan Penilaian Risiko Keselamatan dan Kesehatan Kerja (K3) pada Bengkel Motor di Kota Bogor,” *Factory Jurnal Industri, Manajemen dan Rekayasa Sistem Industri*, vol. 2, no. 2, pp. 46–59, Dec. 2023, doi: 10.56211/factory.v2i2.420.
- [17] M. Nur and Y. Putri Aulia, “Integrasi Metode FMEA dan FTA dalam Strategi Mitigasi Risiko Kecelakaan Kerja (Studi Kasus : PT. Semen Padang),” *Jurnal Teknologi dan Manajemen Industri Terapan (JTMIT)*, vol. 3, no. 4, pp. 393–404, 2024, doi: 10.55826/jtmit.v3i4.483.
- [18] R. Susanti, “Sampling Dalam Penelitian Pendidikan,” *TEKNODIK*, 2005, [Online]. Available: <http://www.pustekkom.go.id>
- [19] A. Widiya Ningsih and M. Albina, “Telaah Kritis Model Mixed Method: Ragam Strategi, Langkah Implementasi, dan Contoh Praktis dalam Penelitian,” *QOUBA: Jurnal Pendidikan*, vol. 2, no. 1, pp. 66–76, Jun. 2025, doi: 10.61104/qb.v2i1.253.
- [20] F. R. Dinanta, “Integrasi Metode Kualitatif dan Kuantitatif dalam Penelitian Manajemen Pendidikan Islam,” *Islamic Management: Jurnal Manajemen Pendidikan Islam*, vol. 1, no. 2, pp. 28–32, 2025, doi: 10.63097/f75r7p71.

- [21] N. Karanikas, D. Weber, K. Bruschi, and sophia Brown, "Identification of systems thinking aspects in ISO 45001:2018 on occupational health & safety management," *Safety sains*, vol. 148, Apr. 2022, doi: 10.1016/j.ssci.2022.105671.
- [22] W. Vera Nurfajriani *et al.*, "Triangulasi Data Dalam Analisis Data Kualitatif," *Jurnal Ilmiah Wahana Pendidikan*, vol. 10, no. 17, pp. 826–833, 2024, doi: 10.5281/zenodo.13929272.
- [23] B. Arianto, *Triangulasi dalam Penelitian Kualitatif*. Balikpapan: Borneo Novelty Publishing, 2024.