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Analysis of Fare Gate Failure Modes and their Impact on Passenger Experience at Malaysia Rapid Transit (MRT) Stations

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Abstract

Fare gate systems are critical components of the Automated Fare Collection (AFC) infrastructure in urban rail transit networks. Frequent failures of fare gate systems may disrupt passenger flow, reduce operational efficiency, and affect service quality, particularly during peak hours. This study investigates the failure trends of fare gate systems in the MRT Kajang Line using historical maintenance records collected from July 2024 to July 2025. A total of 140 failure incidents were analysed using Microsoft Excel through Pivot Table analysis, trend visualisation, and reliability assessment. In addition, a passenger survey involving 124 respondents was conducted to evaluate the operational impact of fare gate failures on commuter experience. The results indicate that the Barrier System was the most failure-prone subsystem, contributing 34.3% of all recorded failures, followed by the power-related failures (20.7%) and Gate CSM-EM subsystem (19.3%). MBC120 capacitor failures were identified as the dominant failure mechanism. Survey findings revealed that fare gate malfunctions significantly affected passenger punctuality and station congestion. This study highlights the importance of systematic failure trend analysis and provides practical recommendations for improving fare gate performance and service reliability in urban rail systems.

1. Introduction

The Automatic Fare Collection (AFC) system is an essential component of modern urban rail transportation, enabling automated fare transactions, passenger access control, and revenue management. Within AFC infrastructure, fare gate systems serve as the primary interface between passengers and the rail network,

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regulating entry and exit to paid areas while ensuring accurate fare validation. As urban rail systems continue to experience increasing ridership demand, the reliability and availability of fare gate systems become increasingly important in maintaining smooth passenger flow, operational efficiency, and service quality (Zhang et al., 2021). Recent studies have highlighted that fare gate performance directly influences station throughput, passenger satisfaction, and overall transit system effectiveness, particularly during peak operating periods when passenger volumes are at their highest (Wang et al., 2024).

Despite their critical operational role, fare gate systems are frequently exposed to intensive usage conditions that may contribute to various failure occurrences. Common failures include sensor malfunctions, mechanical obstruction, actuator degradation, communication errors, and software-related disruptions, all of which can negatively affect gate functionality and passenger movement (Tiongson et al., 2025; Ciszewski et al., 2025). Such failures often result in temporary gate unavailability, passenger congestion, increased waiting times, and reduced operational efficiency. Furthermore, recurring fare gate failures may adversely affect passenger perception of service quality and undermine confidence in the reliability of rail transit services (Cui et al., 2024).

Within Malaysia's MRT network, particularly the MRT Kajang Line (MRT1), fare gate systems operate continuously under high passenger demand and varying operational conditions. Historical maintenance and failure records maintained by the Asset Operations and Management (AOM) Department indicate the occurrence of numerous fare gate failures across multiple stations. However, although extensive maintenance data are routinely collected, these records are primarily utilised for corrective maintenance activities and operational reporting. Limited efforts have been made to systematically analyse historical failure data to identify dominant failure patterns, understand contributing operational factors, and evaluate their effects on system performance.

Current maintenance practices largely rely on reactive maintenance approaches, whereby maintenance actions are performed after failures have occurred (Shaheen et al., 2022). While this strategy restores system functionality, it does not adequately address the root causes of recurring failures or support proactive failure prevention (Barata et al., 2024). Consequently, repeated faults, increased maintenance costs, prolonged downtime, and inefficient resource allocation may continue to affect fare gate performance. Moreover, the absence of comprehensive failure trend analysis restricts the implementation of reliability-centred and data-driven maintenance strategies that could improve system reliability and operational availability.

Furthermore, limited research has been conducted on the relationship between fare gate failures and operational parameters such as time, day, passenger traffic volume, and maintenance cycles within Malaysia's MRT environment. Existing studies predominantly focus on system-level reliability assessment, while detailed analyses of fare gate failure behaviour using actual operational data remain scarce. This knowledge gap hinders the ability of MRT operators to prioritise maintenance activities effectively and optimise asset management strategies based on empirical evidence.

Therefore, this study aims to conduct a systematic failure trend analysis of fare gate systems at selected MRT stations in Malaysia. Specifically, the study seeks to identify the dominant failure modes of fare gate systems based on historical maintenance and failure records, analyse the relationship between fare gate failures and operational parameters, and assess the impact of fare gate failures on system reliability, system availability, and ridership experience. The findings are expected to support the development of more effective maintenance strategies, improve fare gate performance, and enhance the overall reliability and service quality of Malaysia's MRT operations.

2. Methodology

2.1 Research Design

This study adopted a quantitative research design based on reliability engineering and maintenance analytics to investigate the performance of fare gate systems within the Automatic Fare Collection (AFC) system of the MRT Kajang Line. The research utilised historical maintenance and failure records obtained from actual MRT operations to provide an objective assessment of fare gate performance under real operating conditions. The quantitative approach enabled systematic analysis of failure characteristics, identification of dominant failure modes, evaluation of failure trends, and assessment of system reliability and availability using engineering reliability indicators. In addition, a passenger perception survey was incorporated to complement the technical analysis by evaluating the operational impact of fare gate failures from the users' perspective. This integrated approach provided comprehensive, evidence-based findings to support recommendations for improving the reliability and operational performance of MRT fare gate systems. The overall methodology adopted in this study is illustrated in Figure 1.

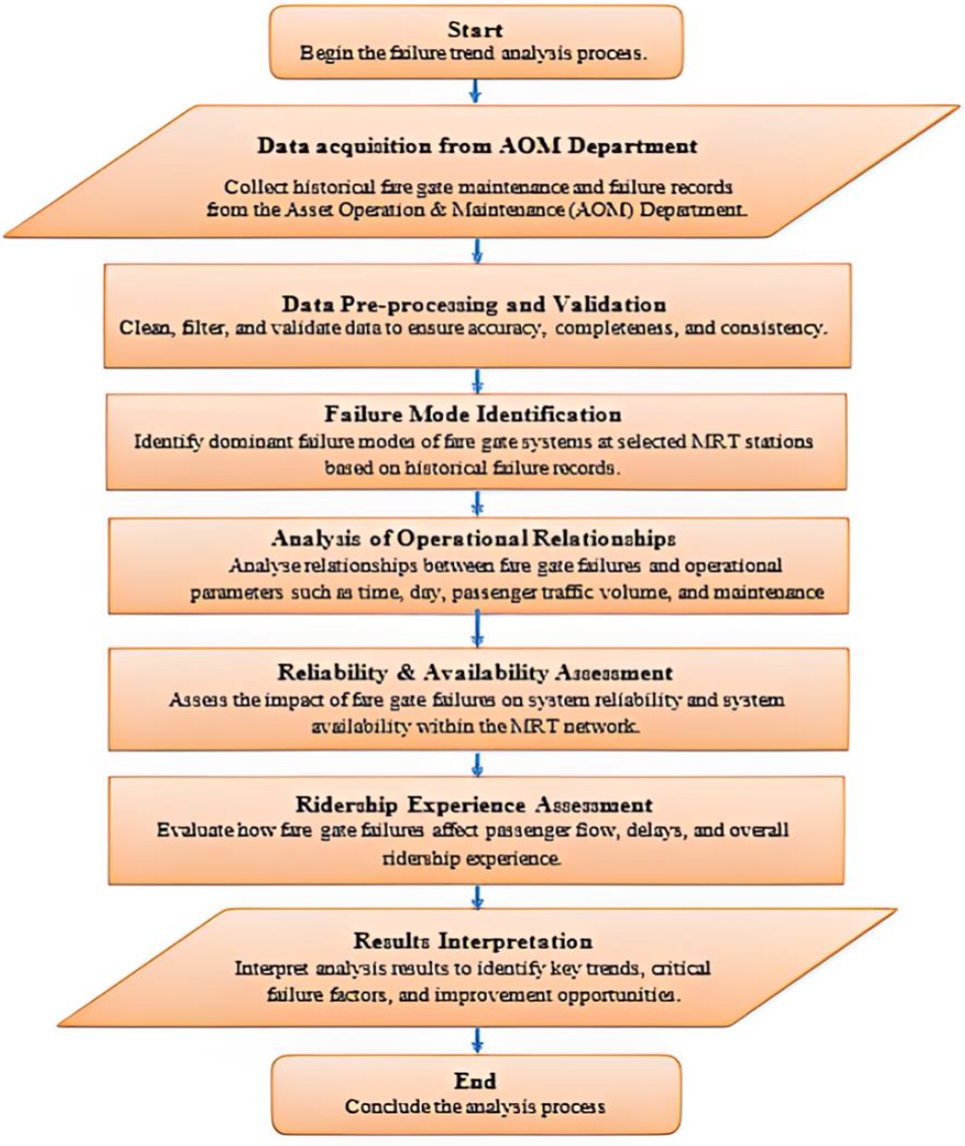


Fig. 1 *Study Flow Diagram of Research Flowchart Design Applied*

Figure 1 illustrates the overall sequence of the research methodology implemented in this study, beginning with problem identification and ending with the formulation of improvement recommendations. The first stage involved defining the research problem, objectives, and scope based on the increasing occurrence of fare gate failures and their impact on MRT service performance. A comprehensive literature review was then conducted to establish the theoretical foundation of the study, covering the Automatic Fare Collection (AFC) system, fare gate components, reliability engineering concepts, maintenance management, and previous studies related to railway asset reliability.

Following the preliminary study, historical maintenance and failure records were obtained from the Asset Operations and Maintenance (AOM) Department of MRT Corporation. These records served as the primary source of operational data for analysing fare gate system performance. Before the analysis, the collected data underwent pre-processing, including data cleaning, validation, standardisation, and organisation to eliminate incomplete, duplicated, or inconsistent records while ensuring data accuracy and reliability.

Once the dataset was prepared, failure mode identification was performed to classify and determine the most frequent causes of fare gate failures based on the recorded maintenance information. The study subsequently analysed failure trends by examining the frequency and distribution of failures across different fare gate subsystems and operational periods. Reliability engineering indicators, including Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), reliability, maintainability, and availability, were then calculated to evaluate the operational performance and maintenance effectiveness of the fare gate system.

To complement the technical analysis, a ridership experience assessment was conducted using a structured questionnaire distributed to MRT passengers. The survey collected passengers' perceptions regarding fare gate failures, including service disruption, waiting time, convenience, and overall satisfaction. The survey findings were analysed to determine the operational impact of fare gate failures on passenger experience and to compare users' perceptions with the actual maintenance performance of the fare gate system.

Finally, the findings obtained from the maintenance data analysis, reliability assessment, and passenger survey were integrated and interpreted to identify the critical factors contributing to fare gate failures. Based on these findings, appropriate recommendations were proposed to improve maintenance planning, enhance system reliability and availability, and support more effective asset management strategies for the MRT fare gate system. This systematic methodology ensured that the research objectives were achieved through a structured, data-driven, and evidence-based analytical process.

2.2 Data Collection

The data for this study were obtained from the MRT Asset Operations and Management (AOM) Department through its Computerized Maintenance Management System (CMMS), which centrally records and manages maintenance activities for the Automatic Fare Collection (AFC) fare gate system. The CMMS served as the primary source of operational data, providing verified maintenance records that reflect actual field conditions.

Within the CMMS, each reported fault was recorded as a work order containing standardized information, including fault descriptions, system classifications, corrective maintenance actions, repair duration, and maintenance status. This standardized recording process ensured traceability of each failure event and supported systematic reliability and maintenance analyses.

The dataset included maintenance logs, fault records, and operational performance information. Maintenance logs documented preventive and corrective maintenance activities, while fault records captured failures such as sensor malfunctions, gate obstructions, communication errors, and card reader failures. Operational data, including passenger flow and fare gate transaction volume, were also incorporated to provide context for analysing system loading conditions and failure occurrence.

The study covered maintenance records from July 2024 to July 2025, involving selected stations from both the MRT Kajang Line and Putrajaya Line. However, the analysis focused primarily on the Kajang Line due to its longer operational history and more comprehensive maintenance records. Its extended service period and higher passenger throughput provided a more robust dataset for identifying recurring failure patterns and evaluating system reliability.

To ensure data quality, only validated records with complete timestamps, clearly defined fault classifications, and confirmed maintenance outcomes were included. Records containing incomplete, inconsistent, or ambiguous information were excluded to improve the accuracy and reliability of the analysis.

All data collection and processing activities were conducted in accordance with MRT Corporation's data governance policies and confidentiality requirements to ensure the ethical use and protection of operational information.

2.3 Data Processing and Failure Classification

The initial stage of analysis involved systematic preprocessing of raw maintenance data obtained from the MRT Asset Operations and Management (AOM) system. The dataset comprised work orders, fault descriptions, timestamps, station identifiers, and maintenance records. However, as commonly observed in operational datasets, several data quality issues were identified, including missing values, duplicated entries, and non-standardised fault descriptions. These issues were systematically addressed to ensure data reliability and analytical consistency.

Records containing missing or incomplete critical attributes, such as work order identification, system classification, fault description, root cause information, or corrective maintenance actions, were excluded from the dataset. This exclusion process was implemented to minimise analytical distortion and to maintain the statistical validity of the dataset. In addition, duplicate work orders resulting from repeated reporting of identical failure incidents were identified and removed to eliminate redundancy and prevent overrepresentation of specific failure events.

Following the data cleansing process, each failure incident was systematically classified based on equipment type, work order complaint (WO Complaint), and work order cause (WO Cause), as illustrated in the study's classification framework. This classification approach was aligned with MRT maintenance documentation standards and further validated through engineering interpretation to ensure operational relevance and consistency with field practices.

The classification framework was developed in accordance with the MRT AOM internal fault taxonomy and was further verified through consultation with maintenance engineers to ensure accuracy and engineering applicability. Based on this structured taxonomy, failure events were categorised into four primary groups, namely mechanical failures, electrical or sensor-related faults, card reader or communication failures, and software or system-related issues. This structured classification provided a consistent analytical foundation and directly supported the identification of dominant failure modes within the MRT fare gate system.

2.4 Failure Trend Analysis

Failure trend analysis was conducted to examine the occurrence, distribution, and characteristics of fare gate failures throughout the study period. Descriptive statistical analysis was first performed to determine the frequency and percentage distribution of failure incidents according to subsystem, component, and failure category. This provided an overall understanding of the failure profile and highlighted the components most frequently affected.

The analysis of dominant failure modes was conducted using a Pareto-based approach, whereby failure categories were ranked according to their frequency of occurrence. Based on the Pareto principle (80/20 rule), a Pareto chart was constructed to distinguish the relatively small number of failure modes that contributed to the majority of recorded failures. This approach enabled the prioritisation of critical failure categories requiring immediate maintenance attention and provided a systematic basis for identifying the key factors affecting fare gate reliability.

Trend analysis was then performed to investigate the relationship between failure occurrences and operational parameters, including the time of day, day of the week, passenger traffic volume, and maintenance intervals. This analysis was used to identify recurring failure patterns, temporal variations, and potential operational factors that influenced the frequency of fare gate failures.

Microsoft Excel was utilised to perform data summarisation, Pivot Table analysis, and graphical visualisation of the maintenance records. Charts and graphs were generated to illustrate failure distributions and trends, facilitating clearer interpretation of the results. Additional figures and detailed analytical outputs are presented in the **Supplementary Materials** to support the findings discussed in this study.

2.5 Reliability and Availability Assessment

The reliability and availability of the MRT fare gate system were evaluated using established reliability engineering indicators, namely Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), reliability, maintainability, and availability. These indicators provide quantitative measures of system performance and maintenance effectiveness under actual operating conditions.

Mean Time Between Failures (MTBF) was calculated to determine the average operating time between two consecutive failures, serving as an indicator of system reliability (Andrzej Żyluk et al., 2023). A higher MTBF value indicates that the fare gate system operates for a longer period before experiencing a failure, reflecting improved operational reliability. Mean Time to Repair (MTTR) was determined to measure the average time required to diagnose, repair, and restore the system to normal operation following a failure. Lower MTTR values indicate more efficient maintenance activities and faster service restoration.

Based on the calculated MTBF and MTTR values, system reliability, maintainability, and operational availability were subsequently evaluated. Reliability represents the probability that the fare gate system performs its intended function without failure over a specified operating period, while maintainability reflects the probability of restoring the system to an operational state within a given repair time. Availability combines both reliability and maintainability to measure the proportion of time that the fare gate system remains operational and capable of providing uninterrupted service to passengers (Lundteigen et al., 2023).

Collectively, these reliability engineering indicators provided a comprehensive assessment of the operational performance of the MRT fare gate system, enabling the identification of maintenance effectiveness, system weaknesses, and opportunities for improving service reliability and operational continuity.

2.6 Ridership Experience Assessment

A structured questionnaire survey was conducted to assess the impact of fare gate failures on passengers' travel experience and to complement the technical reliability analysis. The survey was administered at selected stations along the MRT Kajang Line, targeting passengers who had experience using the Automatic Fare Collection (AFC) fare gate system. A total of 124 respondents participated in the survey.

The questionnaire was designed to collect information on passengers' experiences with fare gate failures, including service delays, congestion, inconvenience during station entry and exit, waiting time, and overall perceptions of fare gate reliability and service quality. The responses also provided insights into the frequency of failure encounters and the perceived impact of these incidents on passengers' travel satisfaction.

The collected survey data were analysed using descriptive statistical methods, including frequency distributions, percentages, and mean scores, to summarise respondents' perceptions and experiences. The findings were subsequently compared with the maintenance and reliability analysis to establish the relationship between fare gate technical failures and their effects on passenger service quality. This assessment provided a user-centred perspective that complemented the operational data, enabling a more comprehensive evaluation of fare gate system performance.

3. Result and Discussion

3.1 Identification of Critical Fare Gate Failure Modes

The analysis of dominant failure modes was conducted using Pareto-based frequency evaluation of AFC maintenance records from July 2024 to July 2025. The results showed that fare gate failures were concentrated in a limited number of subsystems rather than being evenly distributed. At the AFC system level, Ticket Vending Machines recorded the highest number of failures, followed by fare gate systems. However, fare gates were selected as the primary focus due to their direct role in passenger access control and immediate impact on station operations. Any failure at this subsystem directly disrupted passenger flow and caused congestion during peak hours presented in Figure 2.

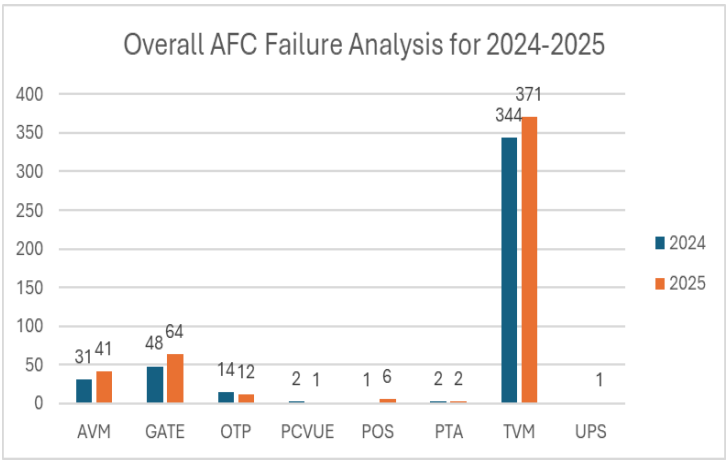
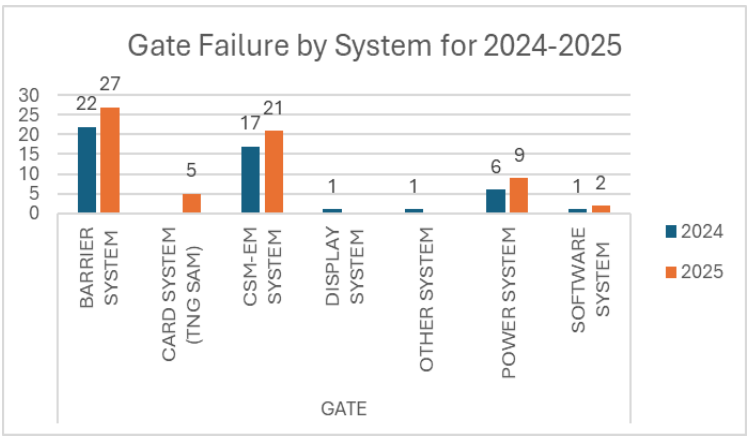
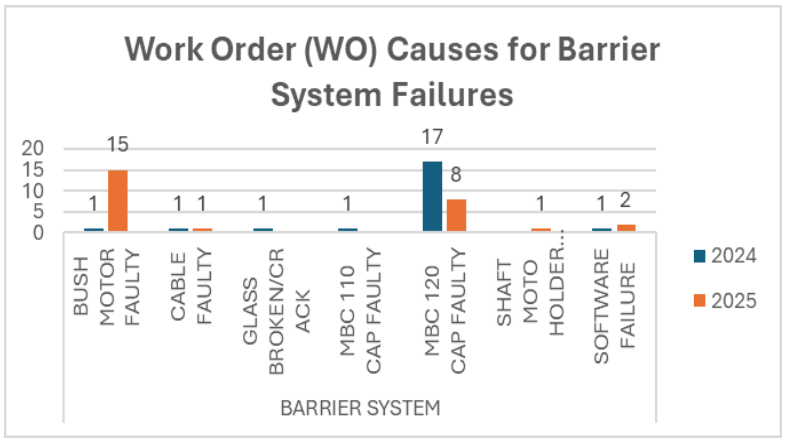


Fig. 2 *Chart of Overall AFC Failure Analysis for 2024-2025*

Pareto analysis confirmed that a small number of failure categories contributed to the majority of system disruptions. Mechanical and electromechanical failures were consistently dominant across both years of study. This pattern followed the 80/20 principle, where a small proportion of failure types generated most operational issues (Vigneshwar et al., 2024). At the subsystem level, the Barrier System recorded the highest failure frequency, followed by the CSM-EM subsystem. Barrier failures were mainly associated with mechanical wear, motor degradation, and repeated actuation cycles. The CSM-EM subsystem failures were linked to control integration issues between mechanical and electronic components presented in Figure 3.



(a)



(b)

Fig. 3 *Bar Chart of Work Order (WO) Causes for Fare Gate System Failures for 2024-2025*

(a) Gate Failure by System; (b) Barrier System Failures

Further analysis of work order causes showed that bush motor faults were the most dominant failure mechanism within the barrier system, with a significant increase from 2024 to 2025. This indicated progressive wear-out behaviour due to continuous operational loading. In contrast, cable-related faults remained minimal, suggesting stable physical wiring conditions. Within the CSM-EM subsystem, control-related faults remained consistently significant, although a slight reduction was observed. This indicated partial improvement but continued vulnerability in electromechanical coordination. Overall, the results confirmed that mechanical and electromechanical subsystems were the primary contributors to fare gate failures. This finding clearly satisfied Objective 1 by identifying the dominant failure modes affecting system reliability presented in Figure 4.

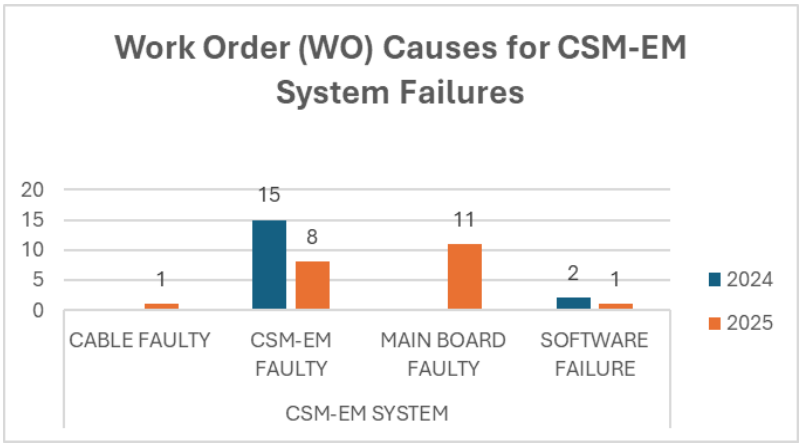


Fig. 4 *Bar Chart of Work Order (WO) Causes for Fare Gate CSM-EM System Failures for 2024-2025*

3.2 Relationship Between Fare Gate Failures and Operational Loading Conditions

The relationship between fare gate failures and operational loading conditions was analysed based on temporal failure trends, passenger flow characteristics, and maintenance cycle evaluation. The results showed that total fare gate failures increased from 48 incidents in 2024 to 64 incidents in 2025, as presented in Figure 5. This increasing trend suggested that fare gate failures were influenced by cumulative operational exposure rather than occurring randomly. In reliability engineering, repeated equipment operation under continuous loading conditions contributes to gradual degradation of components due to wear, fatigue, and material deterioration (Friederich et al., 2024). Therefore, the increase in failure occurrences can be associated with the higher number of operating cycles experienced by fare gate components over time.

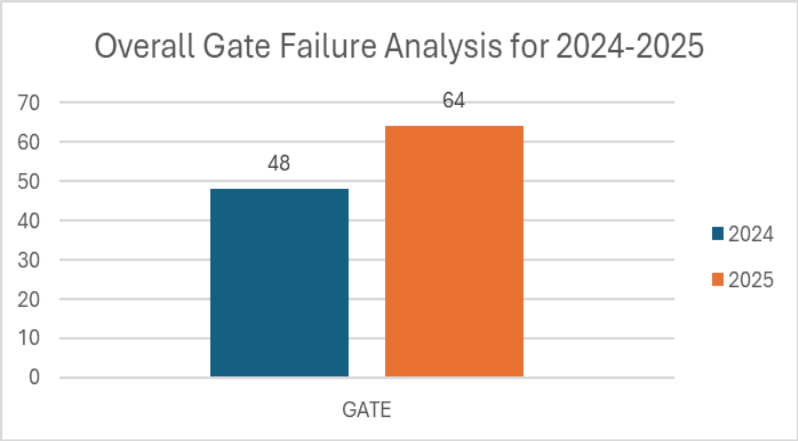
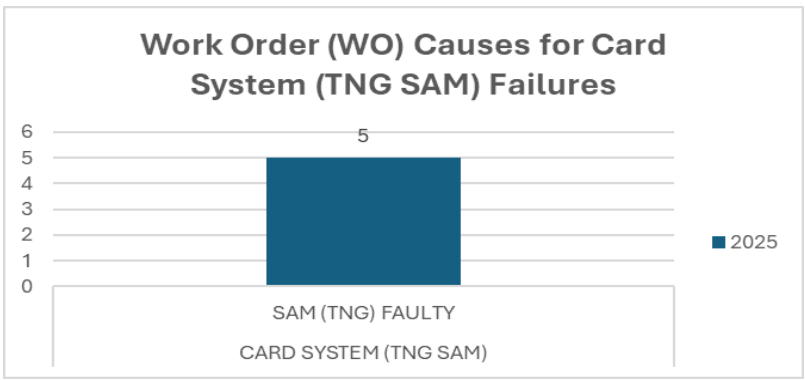


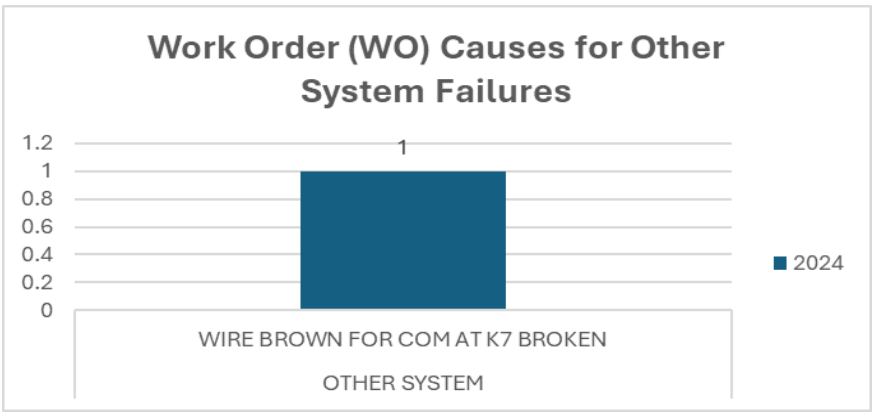
Fig. 5 *Chart of Overall Gate Failure Analysis for 2024-2025*

Higher failure frequencies were observed during periods associated with increased passenger traffic, indicating a relationship between operational loading and system degradation. Increased passenger demand results in higher gate activation frequency, where components such as barrier mechanisms, sensors, and control modules undergo repeated operational cycles within shorter periods. According to fatigue and wear theories, repeated mechanical loading can accelerate component degradation by increasing friction, stress accumulation, and surface deterioration. This condition is particularly significant for automated fare collection systems, where reliability depends on frequent electromechanical interactions between hardware components and control systems.

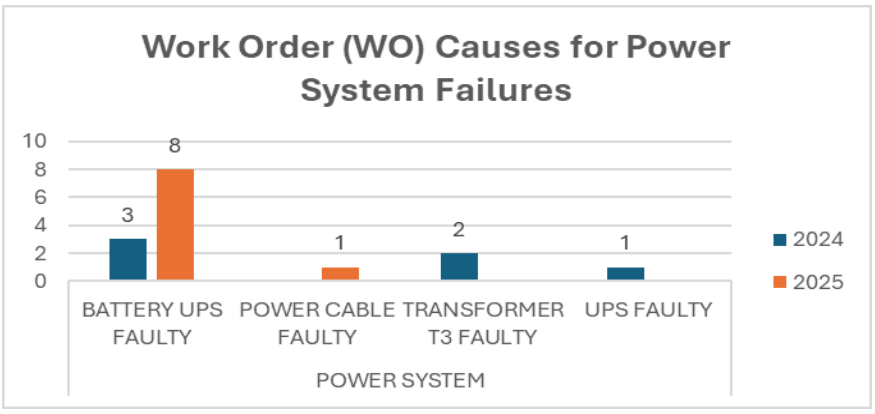
The Barrier System and CSM-EM subsystem demonstrated the highest sensitivity to operational conditions. The Barrier System is responsible for repeated opening and closing movements during passenger entry and exit, causing continuous mechanical loading on moving components such as motors, gears, and barrier mechanisms. Similarly, the CSM-EM subsystem performs essential control and communication functions during each passenger transaction, resulting in frequent processing demands. Therefore, these subsystems are more susceptible to performance degradation compared with less frequently activated components. The distribution of work order causes for different failure categories is shown in Figure 6.



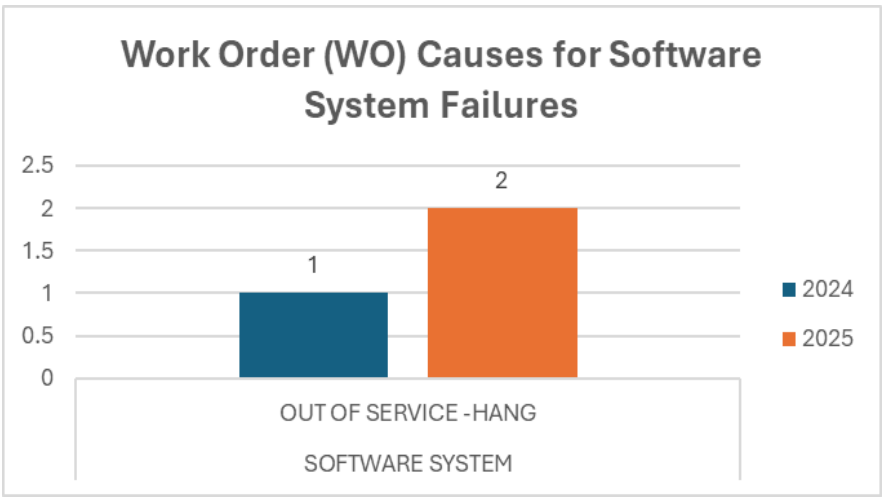
(a)



(b)



(c)



(d)

Fig. 6 *Bar Chart of Work Order (WO) Causes for Fare Gate System Failures for 2024-2025 (a)Display System; (b) Other System; (c) Power System Failures; (d) Software System Failures*

The work order analysis further supported this observation, where mechanical-related issues contributed significantly to fare gate failures. This finding is consistent with previous studies on automated systems, which reported that components exposed to repetitive operational cycles generally experience higher failure rates due to mechanical stress, wear, and fatigue accumulation. In addition, environmental conditions such as dust exposure, temperature variation, and passenger interaction may further contribute to component deterioration and reduce system reliability.

Maintenance cycle evaluation revealed that several failures continued to recur despite scheduled maintenance activities. This indicated that time-based maintenance strategies may not fully represent the actual degradation behaviour of fare gate components. Preventive maintenance performed at fixed intervals may result in either unnecessary maintenance actions or delayed detection of developing faults. Reliability-centred maintenance (RCM) principles suggest that maintenance activities should consider failure behaviour, operational conditions, and component criticality to improve system availability.

The recurrence of similar faults, particularly within the Barrier System, suggested that the existing maintenance approach was still partially reactive, focusing mainly on restoring failed components rather than identifying degradation trends before failure occurrence. Therefore, condition-based monitoring and failure trend analysis could be implemented to improve maintenance decision-making by identifying components with increasing failure probability.

Overall, the findings confirmed that fare gate failures were strongly influenced by operational parameters, particularly passenger demand, usage intensity, and cumulative operating cycles. The relationship between operational loading and failure occurrence demonstrated that higher utilisation levels increased component degradation and contributed to reduced system reliability. These findings successfully addressed **Objective 2**, which aimed to evaluate the relationship between operational conditions and fare gate system failure behaviour.

3.3 Impact of Failures on System Reliability, Availability, and Passenger Experience

The impact of fare gate failures was evaluated using reliability metrics (MTBF and MTTR) and passenger survey responses. The results showed that subsystems with higher failure frequency exhibited lower MTBF values. This indicated reduced reliability under continuous operational conditions. In contrast, MTTR values were higher for complex failures involving electromechanical and control subsystems, which reduced system recovery efficiency presented in Table 1.

MTBF and MTTR Calculating Structure (Operating Period = 1 Year, Total Operating Times = 8760 Hours)						
	2024	2025	Total Failures	MTBF (Hours)	MTTR Range (Hours)	Availability
Barrier System	22	27	49	178.8	4.2	0.977
Card System (TnG SAM)	0	5	5	1752	3.8	0.998
CSM-EM System	17	21	38	230.5	4.0	0.983
Display System	1	0	1	8760	2.5	1
Other System	1	0	1	8760	2.5	1
Power System	6	9	15	584	3.2	0.995
Software System	1	2	3	2920	5.0	0.998
Total	48	64	112			

Table 1 *Excel-Ready MTBF & MTTR Model*

The system availability results presented in Table 1 demonstrate that the operational reliability of the fare gate system was significantly influenced by the frequency of failures and the time required for restoration across different subsystems. Among all evaluated subsystems, the Barrier System recorded the lowest availability value of 0.977, followed by the Power System (0.995) and CSM-EM System (0.983). These findings correspond with the higher failure occurrences recorded for these subsystems, where the Barrier System experienced the highest number of failures, followed by the CSM-EM System. The lower availability of these subsystems indicates that failures occurred more frequently or required longer recovery periods, reducing the overall operational readiness of fare gates.

The reduced availability of the Barrier System can be attributed to its continuous mechanical operation during passenger entry and exit processes. As the subsystem responsible for physical gate movement, components such as motors, mechanical actuators, and barrier mechanisms are exposed to repeated operating cycles, which may accelerate wear, fatigue accumulation, and component degradation (Keeter et al., 2025). Consequently, frequent barrier-related failures directly affected passenger accessibility because unavailable gates reduced the number of operational lanes available at stations, particularly during periods of high passenger demand.

Although the calculated Mean Time to Repair (MTTR) values were relatively moderate, ranging between 2.5 and 5 hours, repeated failures contributed to cumulative operational downtime. For example, the Barrier System recorded an MTTR value of 4.2 hours, indicating that each failure required a considerable recovery period before normal operation could be restored. When failures occur repeatedly, even short repair durations can accumulate into significant downtime, reducing system availability over the analysis period. From an operational perspective, temporary gate unavailability increases passenger dependence on remaining functional gates, which may result in longer queues, slower passenger processing rates, and reduced station circulation efficiency during peak periods.

The CSM-EM System achieved an availability value of 0.983 with an MTBF of 230.5 hours. Although its failure frequency was lower compared with the Barrier System, its impact remained significant due to its critical role in controlling communication and coordination between fare gate components. Any malfunction involving the CSM-EM subsystem may interrupt normal fare gate operation by affecting system control signals, transaction processing, or communication between hardware modules. Therefore, failures within this subsystem require timely maintenance intervention to restore normal passenger access.

In contrast, the Card System (TNG SAM) demonstrated higher availability with a value of 0.998, supported by its lower failure frequency of only five recorded incidents throughout the study period. Similarly, the Display and Other Systems achieved availability values of 1.000, indicating minimal operational disruption caused by these components. However, high availability in these subsystems does not necessarily represent low operational importance, as passenger movement is primarily dependent on the continuous functionality of critical subsystems such as barriers, controllers, and power supply systems. Therefore, maintenance prioritisation should consider both failure frequency and subsystem criticality towards passenger operations.

The passenger survey results further supported the findings from the availability analysis, where respondents reported experiencing fare gate issues including delayed gate response, slow transaction processing, and temporary access blockage. These failures increased perceived waiting time and contributed to passenger inconvenience, particularly during high-demand periods when alternative gates were limited. This demonstrates that fare gate reliability is not only related to equipment performance but also directly influences passenger flow efficiency and overall service quality.

Overall, the availability analysis highlights that improving the reliability of critical subsystems, particularly the Barrier System, CSM-EM System, and Power System, is essential to enhance fare gate performance. Maintenance strategies should focus on condition monitoring, failure trend evaluation, and targeted preventive actions for high-risk components to reduce downtime, increase system availability, and minimise the impact of failures on passenger experience.

3.4 Integrated Reliability–Operational–Human Impact Synthesis of Fare Gate Performance

The integrated analysis of fare gate system performance was conducted by combining three key dimensions: reliability performance indicators, operational loading conditions, and passenger experience outcomes. This approach enabled a comprehensive evaluation of fare gate performance by examining not only the technical behaviour of system components but also the operational consequences and human impact resulting from system failures.

From the reliability analysis, the MTBF, MTTR, and availability results demonstrated that subsystem-level failures significantly influenced the overall operational readiness of the fare gate system. The Barrier System recorded the highest failure frequency and the lowest availability among the evaluated subsystems, indicating that repeated mechanical-related failures were the primary contributor to system degradation. The relatively lower MTBF values of frequently failing subsystems indicated that these components experienced shorter operating periods between failures, while higher MTTR values reflected the time required for troubleshooting and restoration activities. These reliability characteristics suggest that subsystem failure behaviour directly influenced the continuity of passenger access through fare gates.

The operational analysis further revealed that failure occurrence was associated with passenger loading conditions and utilisation intensity. Increased passenger demand resulted in higher gate activation cycles, causing greater operational stress on frequently actuated components such as barriers, sensors, and control modules (Anupriya et al., 2023). The increase in failure incidents from 2024 to 2025 indicates that cumulative operating exposure contributed to progressive component degradation. Therefore, fare gate failures were not solely influenced by equipment ageing but were also affected by the intensity and frequency of daily passenger operations.

The ridership experience survey involving 124 respondents provided additional evidence regarding the human impact of fare gate reliability issues. The survey results showed that 48.4% of respondents were satisfied and 8.1% were very satisfied with fare gate performance, while 40.3% remained neutral and a small proportion reported dissatisfaction (2.4% dissatisfied and 0.8% very dissatisfied). Although the majority of passengers indicated positive experiences, the relatively high neutral response suggested that fare gate reliability issues were still noticeable but not consistently severe enough to significantly reduce overall satisfaction.

Analysis of passenger-reported delay experiences further highlighted the operational impact of fare gate failures. The results showed that 31.5% of respondents experienced delays of 3–5 minutes, 29.0% experienced delays of 1–3 minutes, and 25.8% experienced delays exceeding 5 minutes. These findings indicate that fare gate disruptions could contribute to noticeable waiting time increases, particularly when multiple failures occur simultaneously or during peak passenger periods. Longer delays may occur because passengers are required to queue at alternative operational gates, increasing congestion and reducing passenger flow efficiency.

The survey findings also supported the reliability analysis by demonstrating that technical failures translated directly into passenger-facing impacts. Failures involving critical subsystems such as the Barrier System and CSM-EM System have a greater effect on passenger experience because they directly influence gate opening mechanisms, transaction processing, and passenger movement. In contrast, failures involving less critical components may have limited impact on passengers if alternative functions remain available. Therefore, the severity of a failure should not only be evaluated based on occurrence frequency but also based on its effect on passenger accessibility and service continuity.

The integration of reliability, operational, and human impact analyses demonstrates that fare gate performance is governed by a continuous interaction between equipment condition, operational demand, and passenger perception. Frequent failures reduce system availability, while high passenger loading conditions accelerate component degradation and increase the likelihood of operational disruption. These technical disruptions subsequently influence passenger waiting time, queue formation, and perceived service quality.

Overall, the findings highlight that fare gate reliability management should adopt a holistic approach by considering both engineering performance and passenger experience outcomes. Maintenance strategies should prioritise high-criticality subsystems, particularly the Barrier System and CSM-EM System, while incorporating operational demand patterns and passenger feedback to improve system resilience and enhance MRT service quality.

3.5 Conclusion

This study investigated the failure behaviour and reliability performance of the Automatic Fare Collection (AFC) fare gate system at selected MRT Kajang Line stations through failure trend analysis, operational assessment, and reliability evaluation using maintenance work order records from July 2024 to July 2025. The findings demonstrated that fare gate failures were not random events but were primarily influenced by operational loading conditions and cumulative component degradation.

The analysis identified the Barrier System and CSM-EM subsystem as the dominant contributors to fare gate failures, indicating that frequently actuated mechanical components and critical control systems are the main factors affecting system reliability. Furthermore, the increase in failure occurrences over time and the concentration of failures within high-utilisation subsystems confirmed that continuous passenger interaction and repeated operating cycles contributed to progressive system degradation.

Reliability evaluation showed that although the overall fare gate system maintained high availability, recurring failures of critical subsystems still resulted in operational disruptions that affected passenger flow and ridership experience. The survey findings further highlighted that fare gate issues contributed to increased waiting time, queue formation, and reduced passenger perception of service efficiency during disruption periods.

Overall, this study highlights the importance of implementing targeted preventive maintenance strategies focusing on high-risk subsystems, supported by failure trend monitoring and reliability-based decision-making. The findings provide valuable insights for improving AFC system resilience, reducing operational disruptions, and enhancing passenger service quality in urban rail environments.

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