International Journal of Research in Human Resource Management

E-ISSN: 2663-3361
P-ISSN: 2663-3213
IJRHRM 2025; 7(2): 328-338
Impact Factor (RJIF): 6.16
www.humanresourcejournal.com
Received: 12-08-2025
Accepted: 15-09-2025

K Sunil Kumar
Ph.D. Research Scholar, Department of Management Studies, Christhu Raj College (Affiliated to Bharathidasan University, Tiruchirappalli) Royal Nagar, Panjappur, Viralimalai Road, Tiruchirappalli, Tamil Nadu, India

Dr. SM Soundria
Assistant Professor & Research Supervisor, Department of Management Studies, Christhu Raj College (Affiliated to Bharathidasan University, Tiruchirappalli), Royal Nagar, Panjappur, Viralimalai Road, Tiruchirappall, Tamil Nadu, India

Corresponding Author:
K Sunil Kumar
Ph.D. Research Scholar, Department of Management Studies, Christhu Raj College (Affiliated to Bharathidasan University, Tiruchirappalli) Royal Nagar, Panjappur, Viralimalai Road, Tiruchirappalli, Tamil Nadu, India

Successful implementation of dc metro rail projects despite of its complexity and challenges: An overview from global lookout

K Sunil Kumar and SM Soundria

DOI: https://www.doi.org/10.33545/26633213.2025.v7.i2d.357

Abstract
The fast growth of metro rail systems in metropolitan areas poses a number of difficulties that need to be successfully handled to guarantee project completion. With a focus on rolling stock, maintenance and depot systems, signalling and control, infrastructure, and rolling stock, this research explores the crucial challenges related to metro rail projects. Data were gathered from 125 respondents who represented a range of jobs in different metro projects using a convenience sample technique. In order to comprehend the intricacy of interconnected problems, the study used basic percentage approaches, descriptive statistics, covariance, and correlation procedures. The results show that rolling stock and infrastructure problems are closely related, although maintenance problems have inverse connections with both rolling stock and infrastructure problems. However, there are conflicting correlations between signalling problems and their dynamic role in project integration. The study emphasises how crucial it is to foresee hazards, implement corrective actions, and manage interdependencies across subsystems in order to keep a project moving forward. The findings give stakeholders, project managers, and legislators important information for creating proactive plans for risk reduction and the effective installation of metro rail systems.

Keywords: Thirdrail, rolling stock, Process, project management

1. Introduction

1.1 Background

The fast growth of metro rail systems in metropolitan areas poses a number of difficulties that need to be successfully handled to guarantee project completion. With a focus on rolling stock, maintenance and depot systems, signalling and control, infrastructure, and rolling stock, this research explores the crucial challenges related to metro rail projects. The real frequency dependence of the line causes errors when traction power system fault transient studies utilise a constant inductance and resistance model for rail track impedance. Another research describes a precise frequency-dependent track model for a third-rail metro train. The track feeding impedance is represented by a discrete-component linear circuit network and is synthesised from the self and mutual impedances. The current growth in a third-rail traction system short-circuit failure is simulated using the model. The results, which differ significantly from a constant-parameter track model, are shown for both short and long track section feeding lengths (Fracchia M., *et al*. 1994) [9]. Another study describes the ongoing advancements in neural networks for the real-time identification of DC short circuit issues in DC transportation systems. Prior work has used the Discrete Wavelet Transform to identify any spikes in the waveform of DC third rail current. When a surge occurs, a self-organising neural network receives a feature vector that is extracted from the current waveform via the wavelet transform. Subsequently, the neural network ascertains whether the feature vector results from a normal surge caused by the chopper train commencing or from a fault current surge caused by a short circuit across the DC-link capacitor within a helicopter train. The distinction between the various train beginning and short circuit scenarios has been precisely classified. Using larger datasets for testing and training as well as laboratory application, the neural network's resilience is further demonstrated. The inverter trains are simulated using a novel model.

A novel kind of short circuit defect that happens between the track and the third rail is simulated. An induction motor, lab power supply, and electronic models of railway components are used to meticulously construct a hardware replica of the DC transit system in order to evaluate the defect detection mechanism in a lab setting. The simulation data is used for training two neural networks, and the simulation and laboratory-measured data are used for testing. Both neural networks once more achieve perfect categorisation. Once more, both neural networks obtain perfect categorisation. A useful venue for optimising neural networks and doing in-depth research on the impact of real-world limitations such measurement noises and hardware model nonlinearities is the laboratory setting (Chang CS, *et al.* 2003) [5]. Another study examines the connection between the New York City (NYC) subway's designed layout and the individual resistance of its users. By incorporating rhetorics of individuation into the industrial-corporate machinery, the NYC underground riders have resisted its organising and totalising discourse, challenging the production of anonymous subjectivity that city officials and urban planners have been pursuing. This is demonstrated by the author using Michel de Certeau's theories about urban tactics and strategies as outlined in The Practice of Everyday Life. The study essentially demonstrates how de Certeau's concepts of daily resistance to prevailing power structures which he interprets as being expressed via a language of pedestrian activity are modernised to include people enmeshed in the dehumanising rationalist mechanics of mass transit (Ziegler G., 2004) [24]. Automated external defibrillators (AEDs) should be immediately available in public spaces that are frequently visited. Electromagnetic Interference (EMI) occurs in metro stations and rail terminals. Possible impacts on AED safety and accuracy were investigated in advance of a Public Access Defibrillation (PAD) program in this setting. Techniques: Eleven Distinct AED models were evaluated for sensitivity and specificity of ECG analysis using shock able and nonshockable rhythms supplied by an ECG simulator in standard public transportation environments. The devices were subjected to electromagnetic interference from a tube system that was powered by 750 V direct current (dc) and a rail system that was running on 15 kV alternating current (ac) at a frequency of 16 2/3 Hz. AED wires were positioned perpendicularly and parallel to the tracks, and testing were conducted with incoming trains and at an empty station at a distance of 3 meters from the rails. The findings show Four AED types were deemed inadequate for automated defibrillation in the studied public transport environment due to their unsatisfactory accuracy and safety performance. When the electrode wires are positioned perpendicular to the overhead line and the patient is positioned parallel, interference is reduced. The AED type used for rail or metro stations is determined by how resistant it is to common electromagnetic interference (Kanz KG, *et al.* 2004) [11].

2. Literature Review

Electrified traction lines emit electromagnetic phenomena mostly in the form of magnetic field emissions, which range from low frequency to several MHz. A broader model is put out in another study using the Hertzian dipole equations for the extension to the high frequency region and the Biot-Savart law as a low frequency approximation. It uses a Multiconductor Transmission Line simulator to calculate the current in the line conductors. On a metro line with a third rail system, the data gathered during a measurement campaign is compared with the outcomes (Cintolesi B, *et al.* 2010) [7]. To collect stray current seeping from the running rails and prevent corrosion damage to the system and nearby metallic objects, certain systems, including the Taipei Rapid Transit Systems (TRTS), have used a diode-grounded technique for stray-current collecting. Rail potential, or the high potential between the negative return bus and system earth bus at traction substations, has been seen on the Blue line between BL13 and BL16 during TRTS operation. Since the stray-current collector mats and running rails of the Red-Green and Blue lines meet at the G11 station, the TRTS believes that the impedance bond at G11 is the source of the rail potential increase. The findings of field experiments to determine if the impedance bond at the tie line's G11 affects rail potential and stray currents in TRTS are presented in another research. According to the findings, the rail potential may be decreased by cutting the impedance bond at tie line G11, which prevents the Blue line's negative return current from flowing to the Red-Green Line's rails and vice versa. Additionally, a distributed two-layer ladder circuit model is used to numerically simulate rail potential and stray currents that occur at a Blue line station. When the findings of the field test and the simulation are compared, they show consistency (Tzeng YS, *et al.* 2010) [20]. In the majority of DC electric rail transportation systems, the train current returns via running rails. Stray current returns to the DC supply source through other channels, including adjacent metallic infrastructure, as a result of the resulting rail voltage. The primary cause of corrosion in metallic components near railroads is stray current. Another research examines corrosion phenomena in DC railway traction systems and different earthing methods, such as thyristor, diode, floating, and firmly earthed systems. The safety and corrosive consequences of the stray current caused by different earthing techniques are then compared using simulations. The study is a component of the idea for Tehran Metro Line 3's stray current control. Simulation tests employing a multi-train simulation software tool and Tehran Metro Line 3 system data have corroborated the study's findings. Interesting results from the study include an increase in corrosion damage close to traction substations (Alamuti MM, *et al.* 2011) [2]. In the modern period, energy and environmental sustainability in transportation have become critical. The transport sector was responsible for 27% of the final energy consumption and 6.7 gigatons of CO_2 direct emissions in 2010, according to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. By 2050, baseline CO_2 emissions are expected to almost treble. By 2050, overall transport CO_2 emissions might be lower than baseline increase. In light of this, railway networks are becoming increasingly significant in industrialised nations. They are superior to other modes of transportation for both people and freight because to their excellent energy efficiency. When it comes to passengers, they can transport a lot of people without producing local emissions, which lowers pollution. Using renewable energy sources is facilitated by electrified train lines (Pecharroman RR, *et al.* 2014) [14]. In the past, DC third/four conductor rail electrification systems and overhead contact wire have dominated railway electrification. This has historically been due to the DC traction motor's success and the requirement for a DC supply. Originally, mercury arc rectifiers were employed at substations to rectify DC power that was sent to the traction equipment by overhead wire or conductor rail. The 1950s and 1960s saw the realisation of railway AC electrification systems thanks to the development of mercury arc rectifiers that could be used inside railway vehicles (White RD, 2015) [22]. The approach for optimising the size of an energy storage system (ESS) to maximise the collection of energy regenerated by a train is presented in another study. In addition, efforts have been made to minimise the substation's energy usage in order to maximise return on investment. Here, an examination of a typical rail transportation system structure has been conducted. The transit system's restrictions, including third-rail voltage (catenary) and battery chemistry limits, are taken into consideration throughout the optimisation process. By creating a control strategy in MATLAB Simulink, the findings of the Genetic Algorithm's use to determine the ideal size were verified (Dutta O, *et al.* 2017) [8]. Traction power supply systems (TPSS) with direct current auto-transformers (DCAT) provide advantages in addressing stray current and rail potential problems. Verification in the actual urban rail transit system is challenging and expensive because of the high power level and high operating density in TPSS. In order to validate the output performance of DCAT-TPSS, this study suggests a unique DC traction system hardware emulator (DC-TSHE) that uses static power electronics circuits. A detailed analysis of the rail potential distribution laws of DCAT-TPSS follows the demonstration of the configuration and operating concept. The suggested DC-TSHE's viability is further confirmed by a lab prototype and simulation model. The suggested DC-TSHE's viability and efficiency are confirmed by the modelling and experimental findings (Wang, L., *et al.*, 2018).Since electric rail transportation systems use a lot of electricity, increasing their overall energy efficiency is a problem. To accomplish this goal, a number of methods have been put forth; however, it is not practical to execute and test them all. The best suitable solution for a given system is usually a site-specific problem, hence a precise, verified, and trustworthy simulation tool is essential. A simulation model is offered in another research to investigate wayside energy storage technologies in a DC electric rail transportation system. For the analysis of the transit system's behaviour over time periods ranging from milliseconds to twenty-four hours, the suggested model offers a trustworthy instrument (Khodaparastan M, *et al.*, 2019) [12]. Stray current is becoming a more significant problem as the DC metro system develops quickly. The absence of a stray current collector system (SCCS) and the direct grounding of the track have made the metro depot a vulnerable point in the defence against stray currents. The assessment model of stray current in the metro depot is suggested in this article in order to assess and examine the distribution of stray current in the establishment. The one-way conduction device (OWCD) of the depot is modelled by a current source paralleled with a resistor based on the piecewise-linearized volt-ampere characteristic. Using the nodal analysis approach, the depot's stray current distribution is computed (Lin S, *et al.* 2020) [13]. As the metro continues to grow quickly, a number of issues brought on by the stray current are getting worse. Assessing stray current is the first, but most challenging, step in resolving the issues. In actuality, the metro construction is one of the most significant components of stray current as they are often built using cut-an-cover, shield, and viaduct tunnels. Using the variable metro structures to assess stray current in the long line is important. Another article builds a unified model on this foundation. Multiple differential units are equal to the return current system when the metro structure's variability is taken into account. The real metro structure may be used to determine the differential units at each point. Moreover, the electrical correlations of differential units served as the foundation for uniform equations for stray current solutions. In order to solve the equations for changeable metro constructions, uniform boundary conditions are discussed. Shenzhen Metro's test and simulation data are compared to validate the model. The research concludes with an evaluation of stray current along the long line. It is demonstrated that the stray current is less along the viaduct's lengthy line (Zhou Q., *et al.* 2021) [23]. In addition to increasing energy efficiency, regenerative braking energy recovery for trains can lower the total greenhouse gas emissions from electric rail systems. The quantity of RBE recovered may vary depending on the train's headway duration, track height, track curvature, and speed restriction. The purpose of this study is to look at how these characteristics affect a DC third rail system's RBE recovery. The ETAP-eTraX software has been used to develop a DC third rail system based on the traction power system of the Malaysia Mass Rapid Transit Line 2. Numerous scenarios have been used to assess the impact of changes in the speed restriction, track elevation, track curvature, and train headway time on the RBE recovery. According to the data, the speed restriction has the biggest impact on the quantity of RBE recovery, while the elevation of the track has the biggest impact on the train's overall energy consumption (Chua XR, *et al.*, 2023) [6]. It is well acknowledged that energy storage systems are very successful in increasing the effectiveness of electric rail transit systems. In particular, roadside solutions can greatly improve network receptivity, which will increase the amount of energy saved by regenerative braking. But figuring out the ideal storage device size is a difficult issue. This paper suggests a unique size process based on a multi-objective optimisation framework in order to handle this difficulty. With nonlinear constraints linearised, this framework formulates the issue as a constrained linear least squares problem. Then, using numerical simulations centred on a hypothetical scenario involving a DC rail metro system, the efficacy of this technique is assessed (Andreotti A, *et al.*, 2024) [3]. To explore the possibility of using on board energy storage to power the train into and out of stations with discontinuous electrification, a new model has been developed. This model aims to remove the exposed conductor rail from stations in top contact third rail electrified systems. Despite being a possibly less expensive electrification option, top contact third rail electrified systems offer a serious safety risk because of its exposed conductor rail. It is an alternative to overhead line equipment. For this new discontinuous application, the model can simulate the mechanical, electrical, and energy storage needs. It can also assess the energy requirements, losses, and draws in the application. Depending on the size of the energy storage system, it had the potential to reduce energy consumption by up to 10% when compared to the fully electrified system. It was discovered that employing an energy storage system could effectively bridge 300-meter gaps in the conductor rail within stations with little effect on the scheduled journey time. According to these findings, DC third rail networks can benefit from a discontinuously electrified system that can increase passenger safety while also potentially saving energy in the future (Scott JA, *et al*. 2025) [19].

3. Study Objectives & Research Methodology

This investigation intends to identify the challenges involved in metro rail projects in details. The successful implementation of the project needs a clear view on the challenges and facing it in diplomatic way in advance. It is essential and vital to anticipate the risk and mitigate through the corrective action to back into the track for successful execution of project further it is crucial when multiple system and infrastructure integrated to enable for a complete course of action. Convenience sampling method has been used and around 125 respondents were selected in various metro rail project to access the challenges in various system. To identify the complexity and process involved within. Simple percentage analysis, covariance, correlation and descriptive statistics used to interpret the results. A systematic questionnaire intended to elicit respondents' opinions of the difficulties related to rolling stock, infrastructure, signalling and control, and maintenance and depot systems was used to gather primary data. The survey had both open-ended items to gather qualitative insights and closed-ended questions to aid in quantitative analysis.

4. Results summary

4.1 Factual & percentage analysis

With 52.0% of the 125 respondents being men and 48.0% being women, the gender distribution is pretty balanced. Among employment roles, consulting engineers make up the largest group (16.0%), followed by planning managers (14.4%) and stinger system maintenance engineers (12.0%). Other noteworthy positions include executive engineers (7.2%), signalling project managers (8.0%), power supply project managers (8.8%), and construction managers (10.4%). Project managers in metro projects make up 4.8% of the sample, whereas legal specialists (7.2%), warehouse managers (5.6%), and third rail engineers involved in installation, operations, and management (5.6%) comprise lower numbers. With nearly equal participation of male and female professionals, the profile shows a well-rounded responder base spanning technical, management, legal, and operational professions.

Table 1: Demographic profile of respondents

Gender Profile	**Respondent (N=125)**	**Percentage**
Female	60	48.0%
Male	65	52.0%
Total	125	100.0%
Job Role	Respondent (N =125)	Percentage
Project Manager-metro	6	4.8%
Maintenance Engineer/ Stinger system	15	12.0%
Construction Manager-Projects	13	10.4%
Power Supply Project Manager	11	8.8%
Signalling projects manager	10	8.0%
Executive Engineer-Projects	9	7.2%
Planning manager	18	14.4%
Legal expert	9	7.2%
Warehouse Manager	7	5.6%
Third rail engineers/ Installation/ Operations & Management	7	5.6%
Consulting Engineers	20	16.0%
Total	125	100.0%

According to the poll of 125 participants, over half are B.E./B.Tech graduates (45.6%), followed by M.E./M.Tech graduates (32.0%). A lesser percentage are non-engineering degree holders (12.0%) and IPMA/PMP certified project specialists (10.4%). Regarding age distribution, the majority (45.6%) are in the younger 20-35 age range, followed by the 35-40 age group (32.0%), the 40-50 age group (10.4%), and the 50-60 age group (12.0%). According to the responder profile, the workforce is mostly youthful and technically skilled, with a sizable percentage of engineers backed by a smaller but noteworthy number of senior professionals and certified project specialists.

Table 2: Participant education and Age level

Educational profile	**Respondent (N=125)**	**Percentage**
B.E/B Tech graduates	57	45.6%
ME/ M Tech Graduates	40	32.0%
IPMA/PMP certified Project expert	13	10.4%
Non-Engineering degree holders	15	12.0%
Total	125	100.0%
Age Group	Respondent (N=125)	Percentage
20-35 years	57	45.6%
35-40 years	40	32.0%
40-50 years	13	10.4%
50-60 years	15	12.0%
Total	125	100.0%

The most important issues, according to an analysis of the infrastructure challenges reported by 125 respondents, are substation power selection and civil, mechanical, electrical, and plumbing concerns (16.0%). These are followed by challenges related to geography, civil conditions, and soil conditions (14.4%), as well as passenger ticketing and security issues (13.6%). Installation of the third rail and return cable (12.8%), land acquisition, route, and viaduct finalisation (10.4%), as well as interface problems and numerous contractor engagement (10.4%), are other noteworthy hurdles. Concerns about heat, ventilation, and air conditioning (0.8%) were comparatively low, but other cited issues included metro station fire detection and fighting systems (6.4%) and overhead catenary system stringing (9.6%).The design of rolling stock weight and tare weight was ranked as the most urgent issue by respondents (16.0%), followed by trial runs, headway, and trip scheduling issues (13.6%), wheel and brake set selections (12.0%), and difficulties with bogie selection and integration (11.2%). While worries about power supply devices (4.8%) were relatively smaller, other important difficulties were traction transformer and propulsion problems (6.4%), train control and maintenance systems (10.4%), and passenger information and annunciation systems (11.2%). According to the findings, technological design, integration, and operational preparedness stand out as the most crucial issues facing rolling stock management and infrastructure, respectively.

Table 3: Rolling Stock and Infrastructure Challenges

Infrastructure challenges	Respondent (N=125)	Percentage
Overall design requirement finalization	7	5.6%
finalization of routes, viaduct and Land acquisition issues	13	10.4%
geographical issues, civil, soil condition related issues	18	14.4%
Electric Substation Power selection, Civil, Mechanical, electrical, plumbing issues	20	16.0%
Metro station Fire alarm & fire detection, fighting system	8	6.4%
Metro Heat ventilation & air conditioning system	1	0.8%
Passenger ticketing & security-related matters	17	13.6%
Multiple Contractor involvement & interface issues	13	10.4%
Overhead catenary system pegging plan, stringing issues	12	9.6%
Third rail and return cables design, installation-related issues	16	12.8%
Total	125	100.0%
Rolling stock-related challenges	**Respondent (N=125)**	**Percentage**
designing the rolling stock weight, Tare weight	20	16.0%
number of cars, bogies selection, integration	14	11.2%
passenger in & out flows control	10	8.0%
headway and trip schedules, Trail run, commissioning issues	17	13.6%
power supply/ current collection device selection	6	4.8%
wheel and brakes sets selections	15	12.0%
Passenger information & annunciation system	14	11.2%
Traction Transformer & propulsion system issues	8	6.4%
Train control & maintenance system issues	13	10.4%
Power capacity and Aesthetic requirements related	8	6.4%
Total	125	100.0%

According to a survey of 125 participants, the integration of rolling stock signalling systems with external systems is the most significant challenge in the field of signalling and control (22.4%), followed by problems with the design, installation, and commissioning of signalling equipment (14.4%). Track-turnover signalling interface problems (8.8%), signalling system interface problems (9.6%), and pointing machine and wayside system integration (9.6%) are further noteworthy challenges. The architecture of the operation control centre (7.2%), supervisory control and data collection systems (6.4%), the lack of technically qualified personnel (8.0%), and the need for signalling software changes (4.8%) were also noted as difficulties. The most commonly cited problems with rolling stock maintenance and depots were maintenance, plant, and mechanical failures (18.4%), followed by the application of stingers and offshore power supplies (16.8%) and the appropriateness of depot equipment selection (13.6%). Concerns about depot placement and water supply (12.0%), stabling line and track pit problems (12.8%), and reliability and availability target slips (12.8%) were particularly noteworthy. While rolling stock shunting/lifting and dead movement concerns (1.6% each) were very rare, unit exchange spare issues during overhauls were noted by comparatively fewer responders (6.4%). All things considered, the results highlight the significant technical and integration difficulties that both signalling and depot maintenance must overcome, with system compatibility, equipment dependability, and power infrastructure standing out as the most urgent areas in need of focus.

Table 4: Rolling Stock Maintenance and Signalling challenges

Signalling & control related challenges	Respondent (N=125)	Percentage
Supervisory control and data acquisition/ Distributed control system related	8	6.4%
Operation control centre and Backup control centre design, system-related	9	7.2%
Pointing machine and integration of wayside system with train control systems	12	9.6%
Signalling Equipment design, installation and commissioning related issues	18	14.4%
Signalling system interface issues	12	9.6%
Track, turnover and Signalling interface issues	11	8.8%

Technical skilled manpower issues	10	8.0%
Signalling software and its upgrade-related issues	6	4.8%
Testing and commissioning, trailing and successful demonstration	11	8.8%
Integration of the signalling system in rolling stock with external systems	28	22.4%
Total	125	100.0%
Rolling stock Maintenance and Depot challenges	**Respondent (N=125)**	**Percentage**
Depot equipment selection, suitability	17	13.6%
Prompt response, team training and availability issues	5	4.0%
Reliability and availability target slips	16	12.8%
Selection of depot location and utility water supply issues	15	12.0%
Stinger and offshore power supply implementation	21	16.8%
stabling line, track pit and maintenance line issues	16	12.8%
Maintenance, Plants and machinery failure-related issues	23	18.4%
Rolling stock, Shunting or lifting issues	2	1.6%
Dead movement issues	2	1.6%
Unit exchange spare issues during overhauls	8	6.4%
Total	125	100.0%

4.2 Descriptive Statistics and results

Table 5: Descriptive Statistic

	Infrastructure challenges	**Rolling stock related challenges**	**Signalling & control related challenges**	**Rolling stock Maintenance and Depot challenges**
N	125	125	125	125
Missing	0	0	0	0
Mean	2.82	2.29	2.29	2.26
Std. error mean	0.107	0.0949	0.104	0.105
95% CI mean lower bound	2.60	2.10	2.08	2.05
95% CI mean upper bound	3.03	2.48	2.49	2.46
Median	3	2	2	2
Mode	2.00	2.00	2.00	1.00
Sum	352	286	286	282
Standard deviation	1.20	1.06	1.16	1.18
Variance	1.44	1.13	1.35	1.39
IQR	2.00	2.00	2.00	2.00
Range	4	4	4	4
Minimum	1	1	1	1
Maximum	5	5	5	5
Skewness	0.135	0.387	0.668	0.573
Std. error skewness	0.217	0.217	0.217	0.217
Kurtosis	-0.926	-0.733	-0.323	-0.661
Std. error kurtosis	0.430	0.430	0.430	0.430
Shapiro-Wilk W	0.911	0.881	0.869	0.864
Shapiro-Wilk P	< .001	< .001	< .001	< .001
25^{th} percentile	2.00	1.00	1.00	1.00
50^{th} percentile	3.00	2.00	2.00	2.00
75^{th} percentile	4.00	3.00	3.00	3.00

Note: The CI of the mean assumes sample means follow a t-distribution with N-1 degrees of freedom

According to the descriptive statistics, rolling stock, signalling and control, and depot maintenance challenges clustered closely with lower mean values around 2.26-2.29 (Median=2), indicating relatively moderate concern, while infrastructure challenges (M=2.82, Median=3) emerged as the most critical of the four categories of metro rail project challenges. With replies covering the whole 1-5 range, the distributions are positively skewed, flatter than normal (negative kurtosis), and somewhat varied (SD=1.1), indicating a diversity of opinions among respondents.

Although they slightly overlap across categories, the means' narrow confidence intervals support reliability, and the Shapiro-Wilk test revealed that all variables significantly deviate from normalcy ($p<.001$). Overall, the results show that infrastructure problems are the most urgent concern, with other categories being viewed as less significant but nonetheless equally significant.

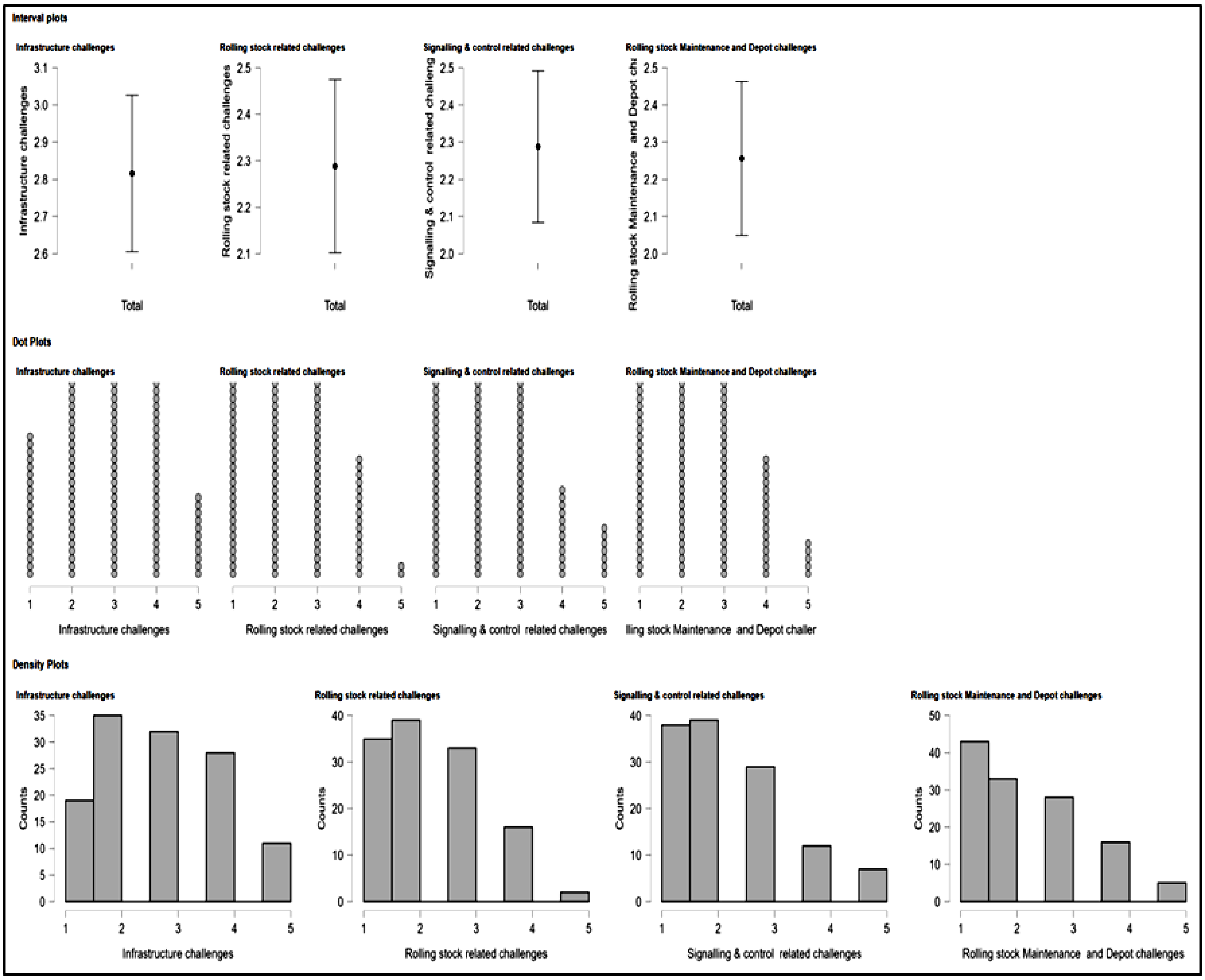

Fig 1: Interval, Dot ad Density plots

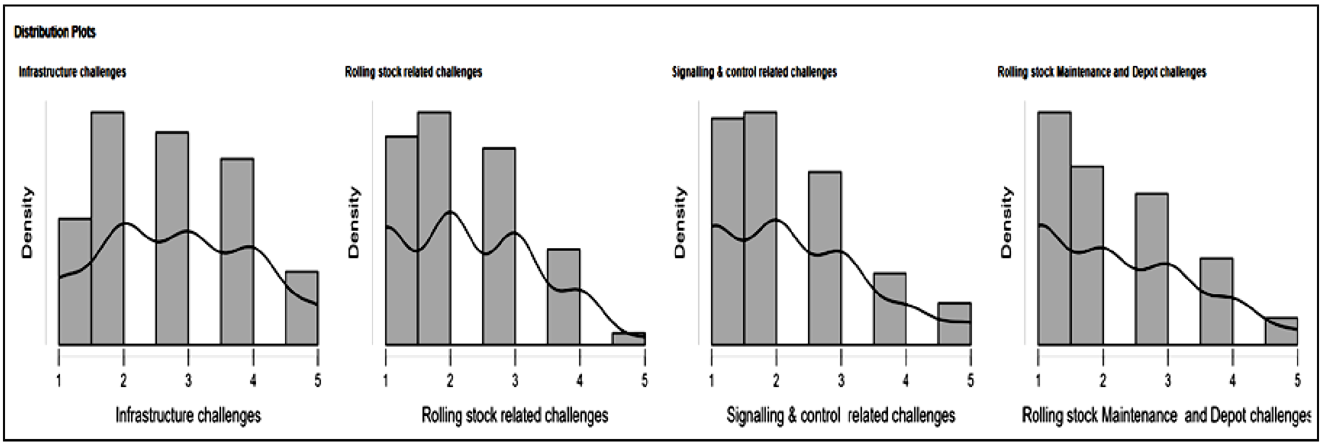

Fig 2: Distribution plots

4.3 Covariance & Correlation Analysis

Table 6: Covariance Matrix results

Covariance	**Infrastructure challenges**	**Rolling stock related challenges**	**Signalling & control related challenges**	**Rolling stock Maintenance and Depot challenges**
Infrastructure challenges	1.442	0.586	-0.116	-0.138
Rolling stock related challenges	0.586	1.126	0.15	-0.195
Signalling & control related challenges	-0.116	0.15	1.352	0.216
Rolling stock Maintenance and Depot challenges	-0.138	-0.195	0.216	1.386

The covariance analysis reveals that infrastructure challenges (variance=1.442) and signalling & control challenges (variance=1.352) show relatively high variability among respondents, indicating diverse opinions, while rolling stock (1.126) and maintenance & depot challenges (1.386) are somewhat more consistent. A moderate positive covariance is observed between infrastructure and rolling stock challenges (0.586), suggesting that respondents who perceive infrastructure issues as significant also tend to view rolling stock as problematic. Similarly, weak positive associations exist between rolling stock and signalling (0.150), and signalling and maintenance (0.216), indicating limited but aligned perceptions. In contrast, negative covariances are seen between infrastructure and signalling (-0.116), infrastructure and maintenance (-0.138), and rolling stock and maintenance (-0.195), implying that higher ratings in one challenge area often coincide with lower ratings in the other. Overall, the analysis highlights a strong interconnection between infrastructure and rolling stock challenges, while maintenance-related issues appear to trade off with both infrastructure and rolling stock concerns, and signalling occupies a more mixed position across relationships.

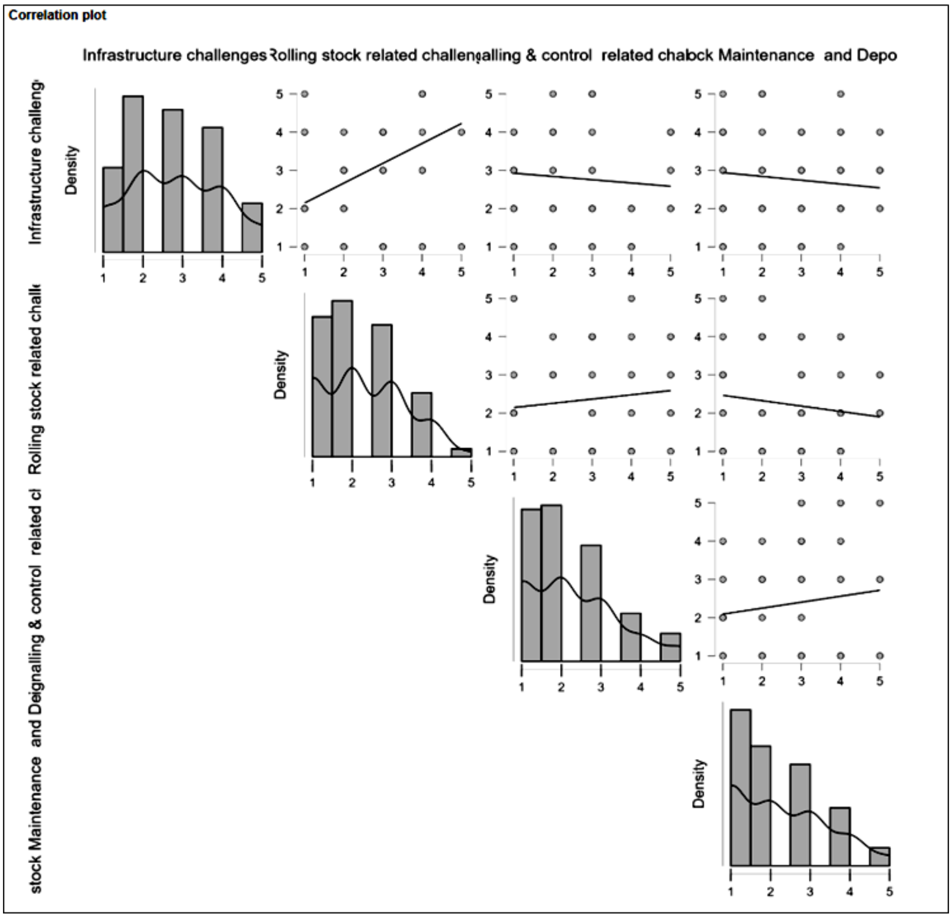

Fig 3: Correlation plots

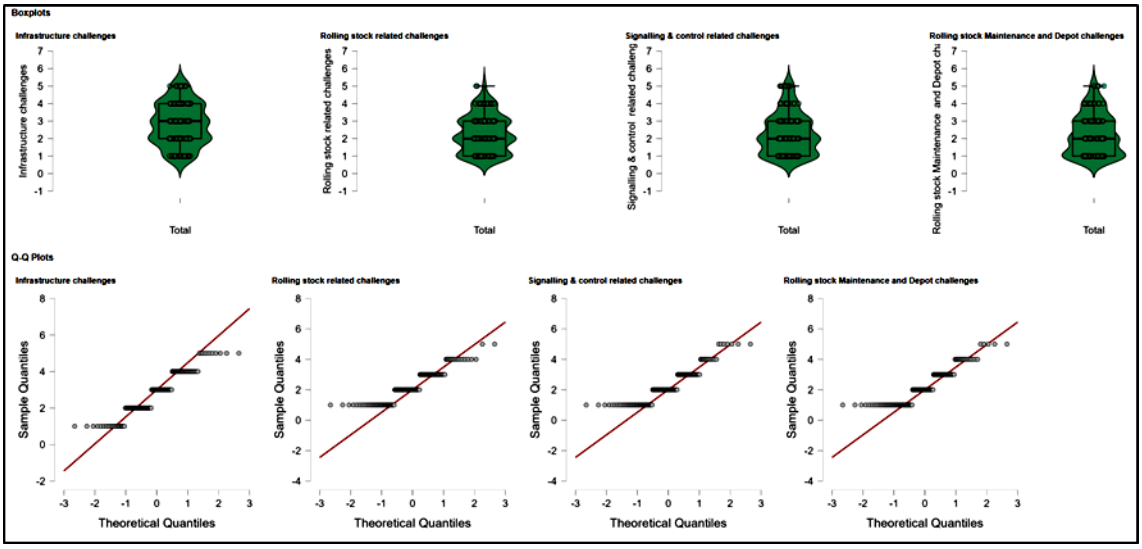

Fig 4: Box plots & QQ Plots distribution

Table 7: Correlation Matrix results

Correlation	Infrastructure challenges	Rolling stock related challenges	Signalling & control related challenges	Rolling stock Maintenance and Depot challenges
Infrastructure challenges	1	0.46	-0.083	-0.098
Rolling stock related challenges	0.46	1	0.122	-0.156
Signalling & control related challenges	-0.083	0.122	1	0.158
Rolling stock Maintenance and Depot challenges	-0.098	-0.156	0.158	1

The correlation analysis shows that infrastructure and rolling stock challenges have a moderate positive relationship (0.46), suggesting that respondents who perceive infrastructure issues as severe are also likely to rate rolling stock challenges as high. Weak positive correlations exist between rolling stock and signalling challenges (0.122) and between signalling and maintenance challenges (0.158), indicating slight alignment in perceptions across these areas. On the other hand, weak negative correlations are observed between infrastructure and signalling (-0.083), infrastructure and maintenance (-0.098), and rolling stock and maintenance (-0.156), implying that when challenges in one area increase, the others tend to be rated slightly lower. Overall, the findings highlight that infrastructure and rolling stock challenges are most closely related, while maintenance challenges appear somewhat inversely related to both infrastructure and rolling stock, and signalling challenges show mixed but generally weaker associations.

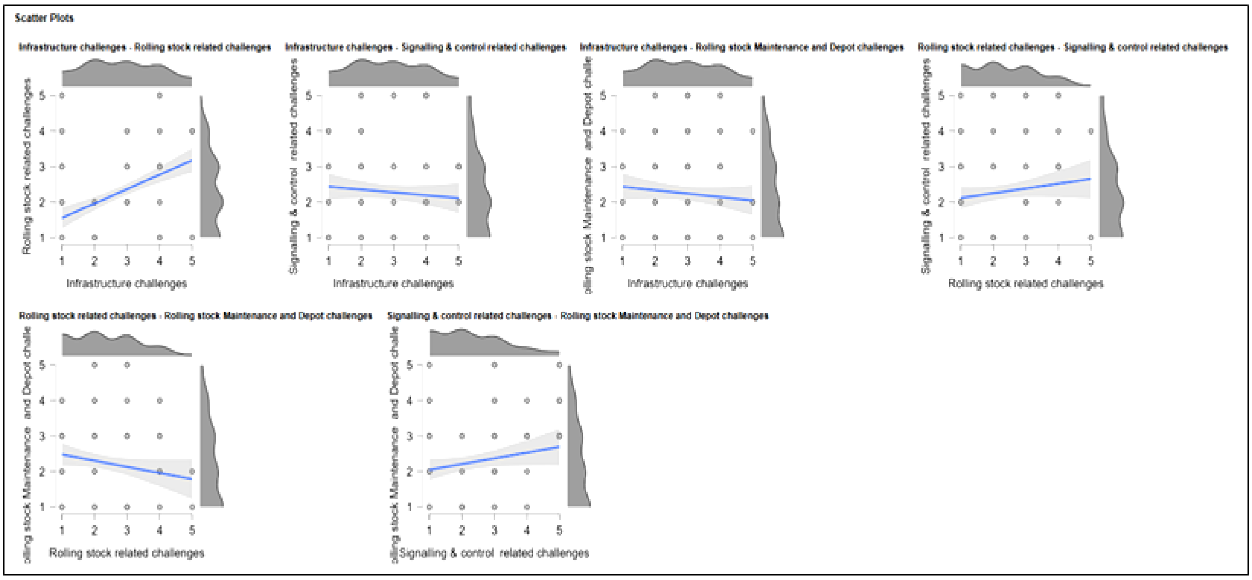

Fig 4: Scatter Plots

5. Discussion

By 2050, 66% of the world's population will live in cities, up from 30% in 1950, according to the Population Division of the United Nations Department of Economic and Social Affairs. Indeed, urbanisation has succeeded in raising demand for infrastructure systems, such as metrorail networks, which are among the most obvious instances of intricate transportation infrastructure systems. The condition of such a system may be perturbed by the synergistic high urban population expansion that occurs at the same time that metrorail use grows significantly. Designing robust, resilient, and sustainable systems that can function well in the face of purposeful and/or stochastic disturbances requires taking these perturbations into account and creating the right resilience metrics. Therefore, it is essential to create resilience measurements in an acceptable and systematic way. Another research investigates metrorail network resilience and related measures that are clearly linked to efficiency and vulnerability, using the Washington, DC Metro as a case study. The failure of a metro station and the failure of a metro segment between stations are the two main failure events that must be taken into account when evaluating the effectiveness and susceptibility of a metrorail network following disruption. The Washington, DC Metro network is used to demonstrate how vulnerability assessment determines the most important stations and train segments. An evaluation of this kind provides a rational foundation for improving system resilience and creating post-failure recovery plans (Saadat Y, *et al.* 2019) [18]. Glass or bulk moulding compound. The third rail electric transportation system makes heavy use of reinforced lastic composite insulators. The local environmental factors that lead to deterioration over time are the main determinant of these insulators' performance. The third rail traction system is at danger for service disruptions and fires due to partial arcing caused by degradation, which intensifies and can result in combustion that ignites combustible debris, smoke, and flames. In certain studies, a thorough examination is carried out to determine the underlying cause of arcing and deterioration in field-aged insulators with 750Vdc ratings. Measurements of surface resistance and leakage current are carried out in polluted, wet, and dry environments. In order to improve interpretation, physico-chemical analyses are carried out using energy dispersive X-ray, Fourier transform infra-red spectroscopy, and scanning electron microscopy to examine surface morphology and chemical changes in the samples. Thermo-gravimetric analysis is also carried out to determine the insulator's thermal properties. The research' intriguing findings unequivocally show that the loss of epoxy material from the bulk eventually exposes glass fibres, which leads in insulator breakdown, arcing, and failure. The research study also emphasises the crucial steps that must be taken in order to identify, isolate, and more accurately predict BMC insulator failures in third rail traction systems (Reddy BS, 2019) [15].

One of the most significant and well-liked transit system types that are utilised on a daily basis in urban places worldwide is rail transport. One of the traction power suppliers in electrified rail systems is the third rail, however it has a number of problems, including insulator failures. Investigating the reasons of insulator failures, which have not been thoroughly examined and reported in the literature, is the aim of this work. In order to achieve this goal, eight third-rail transit systems were chosen in order to study the features of third-rail systems, identify the reasons behind insulator failures, assess the expenses related to insulator failures, and identify mitigating measures to lower the frequency and expense of insulator failures. The findings showed that dirt accumulation was the primary cause of the 17 insulator failure reasons that were found; dirt and carbon dust were found to be the most prevalent particles in third-rail systems. It was observed that in order to lower the frequency and expense of insulator failures, transit agencies frequently employ a variety of mitigation techniques, including cleaning the insulator, carrying out visual inspections, and performing routine maintenance. The results of another research will assist transit system decision-makers in taking prompt action to avoid third-rail insulator failures and in implementing the best practices for their particular transit system (Rouhanizadeh B & Kermanshachi S, 2020) [16]. The transit options accessible globally are the subject of another study. A review and comparison of AC and DC voltage transits are conducted. The distinctions, benefits, and drawbacks of various traction and voltage supply types are highlighted. First, the distinctions between light rail transit, bus rapid transit, metro, and light metro are discussed, with particular focus on the yearly passenger statistics, which characterise the kind of railway transport. The history of DC and AC overhead wires, additional traction preferences for metro transit, and the distinctions between third rail and fourth rail traction are also discussed. Next, the topic of Malaysian transit systems is covered, with particular focus on the LRT Kelana Jaya line, which is the third DC transit system in the world to use fourth rail traction. The discussion has yielded pertinent statistical data, which the study attempts to summarise and compare with previous work on the same topic within the scope of third rail traction. The success of the fourth rail technology is demonstrated by the rise in the number of passengers on the LRT Kelana Jaya line each year (Abd Rahman FA, *et al.* 2020) [1].

Seldom have third rail insulator failures been studied, despite the fact that they frequently cause issues that impact the serviceability of transit systems. Another study creates and classifies preventative techniques, investigates different facets of third rail systems, and pinpoints the reasons behind insulator failures. The findings showed that insulators deteriorate due to local environmental factors, with dirt accumulation being the main cause of failure. Preventing failure was also demonstrated to be highly successful when insulators were maintained and inspected at regular intervals. Preventive measures fall into three categories: safety, regulation, and preventive maintenance programs. Of these, routine inspections are the most commonly implemented. The study's conclusions will be a useful source of knowledge for professionals who deal with third rail systems, assisting them in implementing successful tactics (Rouhanizadeh B & Kermanshachi S, 2021) [17].

Electric motors and transformers may overheat as a result of harmonic distortions in DC third rail systems. Shunt active harmonic filters and single-tuned filters are frequently employed to reduce harmonic distortions. Studies on how train dynamics affect harmonic distortions are scarce, nevertheless. In order to reduce harmonic distortions, a different research will look at how dynamic train behaviours affect a DC third rail system and offer suggestions for the design of SAHFs and single-tuned filters. For the research, MATLAB-Simulink and ETAP-eTraX software are used to model the traction power supply system of a DC third rail system in Malaysia. While MATLAB-Simulink enables the evaluation of the influence of train behaviour on the rail track and the harmonic effect of the railway power network on the train, ETAP-eTraX software is utilised to precisely calculate the train's dynamic behaviour. The results demonstrated that when it comes to tackling dynamic harmonic distortion in traction power supply systems, the SAHF outperforms the single-tuned filter in terms of filtering performance and flexibility. In light of real train consumption patterns, this study highlights the importance of integrating harmonic mitigation devices, especially for controlling dynamic harmonic distortion (Hoo DS, *et al.* 2024) [10]. Rapid Rail Transit (Metro) systems are used in many cities around the world to provide transit users with the mobility and accessibility they need in busy metropolitan corridors that need a high passenger capacity and high-quality service. In the end, metro systems serve as a structural instrument to propel long-term urban spatial and economic growth because of its high capacity, high service level, and environmental performance. Given their need for extremely high capital expenditures on long-lasting assets including rolling stock, stations, guide ways, and related systems (electrification and signalling), metro systems are considered urban megaprojects. The design elements of the system may have a significant impact on its ability, operative tractability, service recital, and cost. Given its impact on system investments, one of the most important design factors is the passenger-carrying capacity in the network's most-demanded segments. Another research study reviews the rail metro technological problems related to their implementation and extension ambitions, based on the most recent public technical data (Barbosa FC, 2024) [4].

6. Conclusion and Limitation of research

The descriptive study's main objective is to identify and analyse the difficulties encountered when implementing metro rail projects. A systematic method was necessary to explore the interrelationships among these difficulties since metro projects include the integration of numerous subsystems, including rolling stock, infrastructure, signalling, and maintenance. Because respondents who were actively involved in various metro rail projects were easily accessible, a convenience sample approach was used. This strategy made it possible to get timely and pertinent data from experts who are aware of the difficulties involved in these kinds of initiatives. One hundred and twelve responders in all, representing various functional areas and positions throughout finished and continuing metro rail projects, were chosen. This sample size was deemed sufficient to ensure feasibility within the parameters of the study and to produce significant findings. To support the primary findings, secondary data including reports, project papers, and current literature were also examined. With insights derived from the comments of participants, the study's scope is restricted to the difficulties faced in certain metro rail projects. Although the convenience sample approach made it easier to reach informed participants, it also restricts how broadly the results can be applied to the metro rail sector as a whole. Furthermore, respondent bias may exist because the study depends on self-reported judgements. Notwithstanding these drawbacks, the study offers insightful information on the intricacy of executing metro rail projects and identifies crucial areas that call for aggressive risk management.

Conflicts of Interest Declaration: All authors declare that we have no conflicts of interest.

References

1. Rahman AFA, Kadir AMZA, Osman M, Amirulddin UAU. Review of the AC overhead wires, the DC third rail and the DC fourth rail transit lines: Issues and challenges. IEEE Access. 2020;8:213277-95.
2. Alamuti MM, Nouri H, Jamali S. Effects of earthing systems on stray current for corrosion and safety behaviour in practical metro systems. IET Electr Syst Transp. 2011;1(2):69-79.
3. Andreotti A, Di Pasquale A, Meo S, Pagano M, Toscano L. Optimal sizing of supercapacitor-based energy storage for dc rail transit systems using an analytic hierarchy process approach. In: 2024 Int Symp Power Electron Electr Drives Autom Motion (SPEEDAM); 2024 Jun; p. 1074-1080. IEEE.
4. Barbosa FC. Rapid rail transit (Metro) system. Implementation and expansion technical and operational challenges review-the DC Metrorail case study. In: ASME/IEEE Joint Rail Conf, V001T06A001. American Society of Mechanical Engineers; 2024 May. p.
5. Chang CS, Xu Z, Khambadkone A. Enhancement and laboratory implementation of neural network detection of short circuit faults in DC transit system. IEE Proc Electr Power Appl. 2003;150(3):344-350.
6. Chua XR, Chua KH, Hau LC, Lim YS, Li W, Bonab MB. Regenerative braking energy recovery of a DC third rail system: A case study of Malaysia Mass Rapid Transit Line 2; 2023.
7. Cintolesi B, Mariscotti A, Merlo D, Mari M. Modeling the magnetic field emissions from a third rail system. In: Electr Syst Aircraft, Railway Ship Propulsion, IEEE; 2010 Oct, p. 1-5.
8. Dutta O, Saleh M, Mohamed A. HESS in DC rail transit system: Optimal sizing and system design. In: 2017 IEEE 6th Int. Conf Renew Energy Res Appl (ICRERA), IEEE; 2017 Nov, p. 908-913.
9. Fracchia M, Hill RJ, Pozzobon P, Sciutto G. Accurate track modelling for fault current studies on third-rail metro railways. In: Proc IEEE/ASME Joint Railroad Conf, IEEE; 1994 Mar, p. 97-102.
10. Hoo DS, Chua KH, Lim YS, Wang L, Rajasekar N. Dynamic harmonic distortion analysis and mitigation strategies for DC third rail systems. Urban Rail Transit. 2024;10(3):200-12.
11. Kanz KG, Kay MV, Biberthaler P, Russ W, Wessel S, Lackner CK, *et al*. Susceptibility of automated external defibrillators to train overhead lines and metro third rails. Resuscitation. 2004;62(2):189-198.
12. Khodaparastan M, Dutta O, Saleh M, Mohamed AA. Modeling and simulation of DC electric rail transit systems with wayside energy storage. IEEE Trans Veh Technol. 2019;68(3):2218-2228.
13. Lin S, Huangfu Y, Zhou Q, Wang A. Evaluation and analysis model of stray current in the metro depot. IEEE Trans Transp Electrific. 2020;7(3):1780-1794.
14. Pecharroman RR, Lopez-Lopez A, Cucala AP, Fernandez-Cardador A. Riding the rails to DC power efficiency: Energy efficiency in dc-electrified metropolitan railways. IEEE Electrific Mag. 2014;2(3):32-38.
15. Reddy BS. Failure analysis of BMC insulators used for third rail traction system. Eng Fail Anal. 2019;101:1-8.
16. Rouhanizadeh B, Kermanshachi S. Third-rail insulator failure causes and mitigating practices: A comparative study of multiple case studies in the US. Urban Rail Transit. 2020;6(4):205-217.
17. Rouhanizadeh B, Kermanshachi S. Development of strategies to prevent third rail insulator failures in transit systems. Urban Rail Transit. 2021;7(1):58-70.
18. Saadat Y, Ayyub BM, Zhang Y, Zhang D, Huang H. Resilience of metrorail networks: Quantification with Washington, DC as a case study. ASCE-ASME J Risk Uncertain Eng Syst B Mech Eng. 2019;5(4):041011.
19. Scott JA, Fletcher DI, Gladwin DT. Onboard energy storage for discontinuous, safer third rail DC electrified rail systems. Proc Inst Mech Eng F J Rail Rapid Transit; 2025. DOI: 10.1177/09544097251351054
20. Tzeng YS, Lee CH. Analysis of rail potential and stray currents in a direct-current transit system. IEEE Trans Power Deliv. 2010;25(3):1516-25.
21. Wang L, Yang X, Xu J, Zheng TQ. DC traction system hardware emulator for rail potential distribution in DCAT traction power supply system. In: 2018 IEEE Int Power Electron Appl Conf Expo (PEAC); 2018 Nov, p. 1-6. IEEE.
22. White RD. DC electrification supply system design. In: 7th IET Prof Dev Course Railway Electrific Infrastructure Syst (REIS 2015); 2015 Jun, p. 1-29. IET.
23. Zhou Q, Lin S, Lin X, Wang A. A uniform model for stray current of long-line DC metro systems. IEEE Trans Transp Electrific. 2021;8(2):2915-2927.
24. Ziegler G. The politics of the third rail. Space Cult. 2004;7(3):283-301.