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Risk Assessment & Safety Management in Lifting Operations for Metro Construction Projects

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Abstract
Lifting operations are critical yet inherently hazardous activities in metro construction projects, involving the movement of heavy equipment, structural components, and materials using cranes and other lifting machinery. These operations pose significant safety risks to personnel, equipment, and the overall project timeline if not properly managed. This project focuses on systematically assessing the risks and implementing effective safety management strategies specific to lifting operations in metro construction environments. The study aims to identify and evaluate potential hazards associated with lifting activities, including mechanical failures, human error, poor ground conditions, inadequate communication, and environmental factors. Through site observations, stakeholder interviews, and incident analysis, the project develops a comprehensive risk profile for lifting operations. The research explores current industry practices, statutory regulations, and international safety standards such as ISO 45001 and OSHA guidelines. An outcome of the project is the development of a structured risk assessment framework and a set of best practices for lifting safety management. This includes the preparation of Lift Plans, competency-based training for operators and riggers, pre-lift inspections, and real-time monitoring protocols. Emphasis is placed on a proactive safety culture, integrating technology such as load monitoring systems and digital permit-to-work platforms. The findings and recommendations of this project aim to reduce accident rates, improve operational efficiency, and ensure regulatory compliance in metro construction projects. This study contributes to safer lifting operations by promoting a risk-informed, systematic approach to safety management in complex urban infrastructure developments.

Keywords: *Lifting Operations, Metro Construction, Risk Assessment, Safety Management, Hazard Identification.*

1. Introduction

The most important elements of metro construction risk management and safety in lifting operations are proximity to workers and the public, existing structures, and complexity of the construction environment and loads to be lifted. Controlled lifting operations use cranes, hoists, gantries, and other mechanical lifters, and un-controlled use of these devices and technology can result in major accidents, delays, and damage. Systematic risk assessment focuses on the identification of hazards, such as equipment and operational failures, overloads, unstable ground, crowded construction sites, restricted sight lines in construction zone(s), and proximity of pedestrians and other workers. After identification, measures can be implemented to avoid the hazards such as lift planning, selection of appropriate lifting devices, ground assessments, and establishment of exclusion zones. Safety management is the practice that operationalizes the planning, defining of responsibilities, training and competency of operators and incident controllers (riggers), and implementation of management and communication systems. Inspection and maintenance of lifting devices and the gear used in conjunction with them must be done to meet the standards and regulations to satisfy the legal requirements of the job. They are done to mitigate the operational risks. The metro systems, lifting operations are done in urban locations with other workers and services that are on the surface. That is where effective risk assessment and safety management are done to ensure the maximum level of safety of the public and that the construction is completed on schedule and the finished structure will be serviceable and durable.

2. Literature Review

Risk assessment and safety management in lifting operations are critical concerns in metro construction projects due to the involvement of heavy equipment, complex environments, and high public exposure. Several researchers have examined construction safety from technological, managerial, and operational perspectives, providing valuable insights relevant to lifting operations. (Kilian Speiser et al., 2025) addressed construction safety knowledge fragmentation through the development of the Unified Ontology for Construction Safety (UNOCS). Their study emphasized that inconsistent and isolated safety data limits effective risk assessment and control [1]. By integrating ISO standards into a unified ontology, UNOCS enhances hazard identification, mitigation planning, and conformance checking. This approach is particularly relevant for lifting operations in metro projects, where standardized terminology and interoperable safety data can support better planning, monitoring, and compliance. (Mohammad Tanvi Newaz et al., 2025) analyzed construction incident trends in New South Wales, Australia, and found a continued increase in incidents despite existing controls. Their study identified high-risk hazards related to moving plants, falling objects, and vehicle collisions all closely associated with lifting operations. The authors highlighted the importance of smart PPE, improved site surveillance, and early design-stage planning, reinforcing the need for proactive safety management in metro construction. (Vikrant Kumar and Nambi Rajan etal., 2024) focused specifically on risk assessment at elevated metro construction sites. Their findings revealed that working at height presents the highest risk, often compounded during lifting activities. The study emphasized the role of Hazard Identification and Risk Assessment (HIRA) in prioritizing risks and reducing accidents through engineering controls and regular safety training. (Govind Raguram Rajan et al., 2023) examined risk management in metro tunnelling projects, stressing that many risks are external and require effective risk transfer and transparent communication. Their work underlined the importance of continuously updating risk registers and learning from past incidents, which is crucial for managing lifting risks in confined underground environments [2]. (Hong Zhou et al., 2023) introduced a cloud evidence based early warning system for tunnel construction safety, integrating BIM, sensor data, and neural networks. Although focused on tunnelling, their dynamic risk prediction model has strong potential for lifting operations by enabling real-time monitoring and early intervention. (Rambabu Pitani etal., 2020) specifically addressed safety practices in lifting operations in metro projects. They highlighted essential controls such as equipment fitness, competent lifting teams, dedicated lifting plans, effective communication, and traffic management. Their study confirmed that structured safety management significantly reduces lifting-related accidents. The literature demonstrates that effective risk assessment, standardized knowledge systems, training, and emerging technologies are to improving safety in lifting operations for metro construction projects.

3. Methodology

3.1. Data Collection

This project involves complex lifting operations as part of a metro construction project located in a dense urban environment. The primary scope includes the planning and execution of multiple heavy and critical lifts for installing prefabricated structural elements, mechanical plant equipment, and HVAC units [3]. Mobile cranes and auxiliary lifting equipment are utilized to lift, position, and secure these components

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with high precision. Due to restricted space, continuous site activities, and proximity to public areas, lifting operations require meticulous planning and coordination. A detailed lifting activity plan has been developed for each operation, clearly defining lift sequences, crane configurations, rigging methods, load weights, lift radii, and control measures. This structured approach ensures safe execution while minimizing interference with parallel construction activities shown in Figure 1.

Literature Review and Data Collection
↓
Site Visits and Observations
↓
Hazard Identification
↓
Risk Analysis and Evaluation
↓
Review of Existing Safety Protocols
↓
Development of Risk Assessment Matrix
↓
Recommendations and Safety Management Plan
↓
Implementation and Monitoring Framework
↓
Documentation and Reporting

Figure 1 Methodology

3.2. Site Visits and Observations

Lifting operations are among the most critical and high-risk activities in metro construction projects due to the handling of heavy loads, the use of complex lifting equipment, and constantly changing site conditions. Effective risk assessment and safety management are therefore essential to prevent accidents, protect workers, and ensure uninterrupted project progress. In this context, site visits and direct observations play a vital role in identifying, evaluating, and controlling risks associated with lifting operations. Site visits provide safety managers, engineers, and supervisors with firsthand exposure to actual working conditions. Unlike document-based assessments, on-site observations enable the identification of real-time hazards, verification of safety measures, and evaluation of how lifting plans are implemented in practice. Metro construction sites are often located in dense urban environments with restricted space, public interfaces, and multiple contractors working simultaneously. Site visits help capture these complexities, which may not be fully reflected in formal risk assessments. During site observations, key aspects such as the condition and setup of cranes, hoists, and rigging equipment are closely examined. The competence and behavior of operators, riggers, and signalers are assessed alongside communication and signaling practices. Environmental conditions, including weather, ground stability, and proximity to public areas, are also monitored. These observations help identify deviations from standard operating procedures, unsafe work practices, or equipment deficiencies that could lead to incidents if not addressed promptly. The dynamic nature of metro construction further emphasizes the need for regular and systematic site visits [4-7]. As work phases progress and site layouts change, new risks may emerge. Continuous observations ensure that risk assessments remain current and safety controls are updated accordingly. Site visits promote direct interaction between safety personnel and the workforce, encouraging feedback, improving awareness, and fostering a strong safety culture. site visits and observations are indispensable tools for effective risk assessment and safety management in lifting operations. They support informed decision-making, enhance compliance with safety standards, and contribute to safer and more efficient metro construction projects.

3.3. Hazard Identification

Understanding hazards is a key part of risk assessment and safety management when it comes to lifting in metro construction projects. Metro construction involves cavity and high-risk environments and complex lifting operations that include the use of cranes, hoists and rigging systems. Because of these environments and the risk involved, working with heavy structural components requires the identification of hazards to mitigate risk and protect workers and the surrounding infrastructure as well as the general public. In metro construction, the

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Table 1 Crane and Equipment Data

Crane Type	Model	Max Load Capacity (SWL)	Boom Length Range (m)	Max Boom Angle (°)	Counter weight Details	Max Lifting Radius (m)	Load Chart Reference	Typical Use in Metro Projects
Crawler Crane	Liebherr LR 1300	300 tons	14 – 98	82°	100 tons (modular)	85	Chart No. LR1300-2025	Lifting TBM components, heavy steel structures
Mobile Crane (All-Terrain)	Grove GMK5 250L	250 tons	13.3 – 70	83°	80 tons (varies with config)	72	GMK5250 L Chart-2024	Installing precast segments, station roof beams
Truck-Mounted Hydraulic Crane	Tadano GT-600EL	60 tons	10 – 43	78°	10 tons (fixed)	38	Tadano GT-600EL Specs	Utility lifts, lighter MEP components
Tower Crane (Luffing Jib)	Potain MR 618	32 tons	30 – 60 (jib)	Variable (15°–85°)	Fixed tower ballast	60 horizontal reach	Potain MR618 Tech Sheet	Station construction, long-reach lifting in narrow sites
Mini Crawler Crane	Maeda MC815	8 tons	6 – 20	80°	Integral ballast	20	MC815 Load Chart	Tunnel interior work, confined space lifting
Rough Terrain Crane	Terex RT 90	90 tons	11 – 47	80°	14.5 tons	40	RT90 Load Chart	Earthworks, heavy lifting in uneven terrain

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Table 2 Crane & Equipment Inspection and Maintenance Records

Equipment Type	Make/ Model	Inspection Type	Inspection Frequency	Inspection Details	Maintenance History Summary	Remarks
Crawler Crane	Liebherr LR 1300	Full Structural & Functional	Monthly & Pre-Lift	Boom, slew ring, winches, control system	Hydraulic system flushed, boom lubrication, replaced limit switch (Aug 2025)	Fit for service
Mobile Crane	Grove GMK5 250L	Load Test & Visual	Weekly, Pre-Use, Annually	Load chart calibration, boom wear, hook inspection	Load test performed (Mar 2025), replaced hoist cable (July 2025)	All systems nominal
Tower Crane	Potain MR 618	Structural, Electrical	Monthly, Annual	Jib connections slew brake, overload protection, mast bolts	Control panel updated, overload sensor recalibrated	Re-inspection scheduled after relocation
Mini Crawler Crane	Maeda MC815	Daily Checklist + Weekly Visual	Daily & Weekly	Tracks, hoist drum, battery level,oil leaks	Filters cleaned, track tension adjusted	Minor oil seepage being monitored
Chain Slings (G80)	Not Applicable (Various)	Visual + Load Tag Check	Before Each Use	Check links, hooks, WLL tags, corrosion	Damaged chain replaced (Aug 2025)	Tagged and color-coded
Wire Rope Slings	4-Leg, 5T sets	Visual + Magnetic NDT (Annual)	Daily Visual Annual NDT	Fraying, broken wires, corrosion, end fittings	NDT passed; minor outer wear noted	Clear for use
Spreader Beam	6m Adjustable	Structural Check	Monthly	Pins, welds, deformation, load rating label	Load test certified (May 2025)	No defects found

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Shackles (12T)	Crosby / Alloy Steel	Visual + Pin Lock Test	Weekly	Pin engagement , wear, deformation	2 shackles replaced after failed test (Aug 2025)	In service, tagged green
Outriggers + Mats	Crane-Specific	Ground Stability + Level Check	Per Lift Setup	Pad settlement, ground pressure test	No anomalies; ground verified by civil engineer	Approved for today's lift

Table 3 Rigging Equipment Condition Report

Rigging Equipment Type	Specification / Capacity	ID/Tag No.	Inspection Frequency	Condition Observed	Certification Status	Usability Status	Remarks / Action Taken
Wire Rope Sling (4-Leg)	5T, 3m, IWRC	WRS-203	Daily visual + Monthly	Good, minor wear on outer strands	Valid till 2026-03	Fit for use	Scheduled for lubrication
Polyester Webbing Sling	3T, 2m, Flat Eye	PWS-112	Before each use	Faded color, stitching intact	Valid	Fit for use	Monitor color loss, still functional
Alloy Steel Shackle (Bow)	6.5T WLL	SH-B6.5-47	Weekly + Pre-lift	No deformation or wear, pin secure	Certified, 3rd-party (Jan 2025)	Fit for use	None
Alloy Steel Shackle (D-Type)	12T WLL	SH-D12-09	Weekly	Pin thread slightly worn	Due for recertification (Oct 2025)	Fit with caution	Replace if wear increases
Chain Sling (Grade 80)	2-Leg, 5T, 3m	CHS-2L-033	Weekly + Pre-lift	Slight rust on one leg	Valid	Fit for use	Scheduled for rust removal
Spreader Bar (Adjustable)	3m–6m, 10T	SPB-10T-007	Monthly	No visible deformation, bolts tight	Load tested (May 2025)	Fit for use	Clear for upcoming girder lift
Wire Rope Sling (2-Leg)	3T per leg	WRS-2L-118	Daily visual + Monthly	Outer layer shows minor fray	Valid till 2026-04	Fit for use	Monitor fray – flag if worsens

Synthetic Round Sling	5T, 2m	SRS-5T-015	Pre-use visual	Abrasion noted near eye	Certified, tag legible	Fit with caution	Marked for close monitoring
Turnbuckle + Hook Set	2T, adjustable	TBK-2T-21	Monthly	No thread damage, free movement	Valid	Fit for use	Lubricated threads, no issues
Lifting Beam Modular	12T capacity, 5m span	LBM-12T-003	Monthly + Per lift plan	All bolts and welds checked	Certified, test loaded	Fit for use	Scheduled for next annual NDT

Table 4 **Crane Position and Outrigger Support Design**

Crane Type / Model	Lift Location / Area	Ground Condition	Crane Positioning Method	Outrigger Load (Per Leg)	Support Pad Type	Support Pad Dimensions (L×W×H)	Engineering Approval Required	Monitoring Method	Remarks / Action Taken
Liebherr LR 1300 (Crawler Crane)	TBM Assembly Shaft – Zone A	Compacted Soil with Stone Bed	Centered on reinforced pad over soil	N/A (crawler tracks)	Steel mat + timber cribbing	2.5m x 4.5m base plates	Yes – Structural & Geotechnical	Load sensors under track pads	Slope checked; pad pre-leveled
Grove GMK5250L (Mobile Crane)	Station Roof Lift – Zone C	Paved surface over tunnel slab	Positioned perpendicular to girder span	120 kN per leg	Steel + laminated hardwood pads	1.8m x 1.8m x 150mm	Yes – due to tunnel below	Daily visual + tilt sensor	Tunnel slab capacity confirmed by design engineer
Potain MR 618 (Tower Crane)	Mezzanine Level – Shaft 3	Concrete foundation	Anchored to embedded bolts	Fixed tower – no outriggers	Base frame with ballast	5.0m x 5.0m frame	Yes – during tower base setup	Tower plumb checks, total station	Anchoring bolts torqued to spec
Tadano GT-600EL (Truck Crane)	MEP Equipment Lift – Shaft Access Road	Compacted soil + PCC ramp	Parallel to access ramp	65 kN per outrigger	HDPE + steel plate combo	1.5m x 1.5m x 120mm	No (surface graded by civil team)	Bubble level + manual checks	Tight setup space; outriggers extended symmetrically
Maeda	Tunne	RC	Direct	N/A	Rubber	N/A	No	Operator	Used only

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MC815 (Mini Crawler)	l Interior – Invert Level	slab, flat	track setup		track pads			visual checks	for low-risk component placement
Terex RT 90 (Rough Terrain Crane)	Open Shaft – Utility Yard	Natural gravel + compacted soil	Positioned on levelled gravel pad	90 kN per outrigger	Timber mat over steel plate	2.0m x 2.0m x 100mm	Optional	Levelling gauge, pad deflection	Gravel re-compacted after rain
Demag AC 220-5 (All Terrain)	Portal Beam Lift – Zone D	Asphalt with underlying slab	Positioned using laser-levelling	135 kN per leg	Solid steel mats with neoprene	2.0m x 2.5m x 200mm	Yes – for over-slab load analysis	Load cell + inclinometer	Asphalt condition reviewed by site civil engineer

process of hazard identification is multi-faceted. It is the construction of systems meant to identify potential sources of construction related harm. In Metro construction, the construction related hazards are of the equipment, load, environment and the people using them [8-14]. Using the equipment in a construction environment with limited to no visibility, in proximity to existing infrastructure or people, and with restricted or high risk behaviors, all add to the construction risk . If the lifting operations are also in conjunction with other tasks of construction, the risk of collisions, miscommunication, and unsafe co-working interactions is compounded. Effective hazard identification also ignores many values that some may hold, identifying as merely using the equipment, with no overloading to the construction components. These also involve components including a lack of adequate construction, a lack of construction in a timely manner, a lack of optimum use of the components that are also carrying construction high risk together. As the first part of the construction of construction, the completion of the construction is the first process in building construction. It is the first fundamental component of construction in high risk construction systems shown in Tables 1-4.

3.4. Risk Analysis and Evaluation

Risk analysis and evaluation are essential components of the risk assessment process for lifting operations in metro construction projects. After hazards are identified, these steps help determine how likely a hazardous event is to occur and how severe its consequences may be. Metro lifting operations involve heavy and bulky loads such as precast concrete segments, steel reinforcements, and machinery, often carried out in confined underground spaces or congested urban areas. These conditions significantly increase both the probability and impact of accidents, making systematic risk analysis vital. Risk analysis focuses on assessing likelihood and consequence. Likelihood assessment evaluates the probability of an incident based on factors such as equipment condition, maintenance history, operator competence, communication systems, and environmental conditions. Consequence assessment examines the severity of potential outcomes, which may range from minor injuries to fatalities, major equipment damage, or project delays. In metro construction, confined spaces and limited escape routes can greatly intensify the consequences of lifting incidents. Risk evaluation follows analysis by comparing calculated risk levels with predefined

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acceptance criteria based on regulations, industry standards, and organizational policies. Risks classified as high are considered unacceptable and require immediate mitigation, while medium risks demand effective control measures. Through structured risk analysis and evaluation, project teams can prioritize hazards, apply appropriate controls, and ensure lifting operations are carried out safely and efficiently within metro construction environments.

3.5. Review of Existing Safety Protocols

The review of existing safety protocols is a crucial step in strengthening risk assessment and safety management for lifting operations in metro construction projects. Due to the involvement of heavy lifting equipment, confined spaces, and complex site conditions, well-defined safety procedures are essential to minimize accidents and operational disruptions. This review examines current regulatory requirements, organizational safety systems, and site-level practices to evaluate their effectiveness and identify gaps. Metro construction projects generally operate under statutory regulations and organizational Safety Management Systems aligned with standards such as ISO 45001 and OSHA guidelines. These frameworks mandate certified equipment, trained personnel, regular inspections, lift planning, and permit-to-work systems. While such protocols provide a solid foundation, their effectiveness often depends on consistent implementation and active supervision. In many cases, safety procedures exist primarily as documentation, with limited enforcement at the operational level. The review also highlights challenges related to lift planning quality, equipment inspection practices, workforce competency, and communication, especially in underground environments. Emergency preparedness and incident management procedures are often documented but insufficiently tested through drills and feedback mechanisms. Overall, the review indicates that although existing safety protocols are comprehensive in structure, gaps in execution, monitoring, and continuous improvement reduce their effectiveness. Addressing these gaps is essential for enhancing lifting safety performance in metro construction projects.

3.6. Development of Risk Assessment Matrix

The development of a risk assessment matrix is a key step in strengthening risk management for lifting operations in metro construction projects. Lifting activities involve complex interactions between heavy equipment, personnel, materials, and constantly changing site conditions. In metro construction, these risks are amplified by confined underground spaces, restricted access, and proximity to critical infrastructure and public areas. A risk assessment matrix provides a structured and visual tool to evaluate these hazards by combining the likelihood of occurrence with the severity of potential consequences. The primary objective of the matrix is to transform qualitative hazard identification into a practical and quantifiable decision-making tool. A semi-quantitative methodology was adopted, using defined likelihood and severity rating scales aligned with international standards such as ISO 45001 and OSHA guidelines. Likelihood ratings reflect factors such as equipment condition, operator competence, and frequency of lifting activities, while severity ratings address the potential impact on personnel, equipment, and project continuity. Multiplying likelihood and severity scores, overall risk levels are determined and categorized as low, medium, high, or extreme. This classification enables clear prioritization of hazards and supports the selection of appropriate control measures. The developed 5×5 risk matrix allows supervisors and safety personnel to quickly assess lifting risks before operations commence. Overall, the risk assessment matrix promotes consistency, transparency, and proactive safety management, contributing significantly to safer lifting operations in complex metro construction environments.

3.7. Recommendations and Safety Management Plan

Lifting operations in metro construction projects present significant risks due to heavy loads, confined underground spaces, complex site conditions, and simultaneous activities. Based on the risk assessment findings, a structured set of recommendations and a comprehensive safety management plan are essential to minimize accidents and improve operational safety. The proposed plan integrates engineering,

Table 5 Risk Analysis of Lifting Hazards

Hazard	Likelihood (L)	Severity (S)	Risk Score (L×S)	Risk Level
Crane mechanical failure	3	5	15	High
Overloading of crane	2	5	10	Medium
Improper rigging	4	3	12	High
Load swing	4	3	12	High
Poor ground condition	3	4	12	High
Poor lighting (underground)	5	3	15	High
Operator fatigue	3	3	9	Medium
Communication failure	4	3	12	High
Proximity to live utilities	2	5	10	Medium
Adverse weather	3	3	9	Medium

Table 6 Risk Analysis

Severity Likelihood	1Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
5 Almost Certain	5 (M)	10 (H)	15 (H)	20 (E)	25 (E)
4 Likely	4 (L)	8 (M)	12 (H)	16 (E)	20 (E)
3 Possible	3 (L)	6 (M)	9 (M)	12 (H)	15 (H)
2 Unlikely	2 (L)	4 (L)	6 (M)	8 (M)	10 (H)
1 Rare	1 (L)	2 (L)	3 (L)	4 (L)	5 (M)

Legend:
L = Low Risk
M = Medium Risk
H = High Risk
E = Extreme Risk

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Page No: 2620-1203
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Table 7 Quantitative Risk Evaluation of Lifting Hazards

Hazard	Likelihood (Score)	Consequence (Score)	Risk Score (L×C)	Risk Level	Risk Acceptability
Equipment failure (crane collapse)	3	5	15	High	Unacceptable
Overloading lifting equipment	2	5	10	Medium	Requires control
Improper rigging causing load swing	3	3	9	Medium	Requires control
Poor lighting underground	5	3	15	High	Unacceptable
Operator fatigue	3	3	9	Medium	Requires control
Proximity to live electrical cables	2	5	10	Medium	Requires control
Weather conditions (wind gusts)	3	3	9	Medium	Requires control
Confined space constraints	5	3	15	High	Unacceptable
Poor communication among team	3	3	9	Medium	Requires control
Lack of emergency procedures	2	5	10	Medium	Requires control

Table 8 5×5 Risk Assessment Matrix

Likelihood / Severity	1	2	3	4	5
5	5 (M)	10 (H)	15 (H)	20 (E)	25 (E)
4	4 (L)	8 (M)	12 (H)	16 (E)	20 (E)
3	3 (L)	6 (M)	9 (M)	12 (H)	15 (H)
2	2 (L)	4 (L)	6 (M)	8 (M)	10 (H)
1	1 (L)	2 (L)	3 (L)	4 (L)	5 (M)

(L = Low, M = Medium, H = High, E = Extreme)

Table 9 RPN-Based Risk Prioritization

Hazard	L	S	D	RPN	Priority
Crane failure	3	5	4	60	Very High
Poor lighting	5	3	4	60	Very High
Confined space	5	3	3	45	High
Load swing	4	3	3	36	Medium
Communication failure	3	3	2	18	Low

administrative, and procedural controls in line with international standards and industry best practices.
Recommendations include the use of certified and well-maintained lifting equipment, regular inspections, and the adoption of load monitoring and anti-sway technologies to reduce mechanical and load-related failures. Administrative controls such as detailed lift planning, permit-to-work systems, competency-based training, and effective communication protocols are critical to managing human and organizational risks. Fatigue management through proper work scheduling further enhances operational reliability. The safety management plan is structured across pre-lift, during-lift, and post-lift phases to ensure systematic risk control at every stage of lifting operations. Pre-lift risk assessments, clear role allocation, and team briefings establish preparedness, while continuous supervision and environmental monitoring during lifts ensure compliance. Post-lift inspections, reporting, and feedback support continuous improvement. Overall, implementing these recommendations will strengthen safety performance, reduce lifting-related incidents, enhance regulatory compliance, and foster a proactive safety culture in metro construction projects.

3.8. Implementation and Monitoring Framework

An effective implementation and monitoring framework are essential to ensure that the safety management plan for lifting operations in metro construction projects is applied consistently and delivers measurable results. Given the high-risk nature of lifting heavy loads in confined underground environments, the framework provides a structured approach for executing safety measures, tracking performance, and enabling continuous improvement. Implementation begins with clearly defined roles and responsibilities, supported by dedicated safety committees and trained personnel. Engineering and administrative controls, including approved lift plans, permit-to-work systems, equipment inspections, and emergency procedures, are systematically integrated into daily operations. The use of technology such as load monitoring systems, digital permits, and incident reporting tools further strengthens control and accountability. Monitoring focuses on regular inspections, audits, and performance measurement using key performance indicators such as incident rates, compliance levels, training completion, and equipment downtime. Daily checks, weekly reviews, and periodic management audits ensure early detection of unsafe conditions and prompt corrective action. Statistical analysis of incidents and near-misses supports trend identification and risk reassessment. A continuous feedback mechanism ensures lessons learned are incorporated into updated procedures, training programs, and risk assessments. Overall, this framework promotes proactive risk management, sustained compliance with safety standards, and a strong safety culture, contributing to safer and more efficient lifting operations in metro construction projects explained in Tables 5-11.

3.9. Documentation and Reporting

Documentation and reporting are essential elements of safety management for lifting operations in metro construction projects. Due to the high-risk nature of handling heavy loads in confined and complex environments, systematic record-keeping ensures that lifting activities are properly planned, controlled, and reviewed. Effective documentation supports regulatory compliance, enhances accountability, and provides a reliable basis for audits, incident investigation, and continuous safety improvement. Documentation is required at all stages of lifting operations. During the planning stage, lift plans, risk assessments, equipment inspection records, and personnel competency certifications must be prepared and approved. During execution, observations, communication logs, permit-to-work updates, and any deviations from approved plans are recorded. Post-lift documentation includes equipment condition reports, near-miss or incident records, and corrective actions taken. In the event of an accident, detailed incident reporting and root cause analysis are essential to prevent recurrence. The use of standardized templates and digital documentation tools, such as electronic permit systems and mobile reporting applications, improves accuracy, traceability, and accessibility of records. Compliance with standards such as ISO 45001, OSHA, and local

Table 10 Risk-Based Safety Recommendations

Hazard	Risk Score	Recommended Control	Priority
Crane mechanical failure	15	Preventive maintenance, load testing, operator training	Very High
Improper rigging	9	Rigger certification, taglines, supervision	High
Load swing	12	Anti-sway devices, controlled lift speed	High
Poor lighting underground	15	Install LED lighting, plan lifts during light hours	Very High
Operator fatigue	9	Work-rest cycles, shift rotation	High
Electrical proximity	10	De-energize lines, maintain clearance	Medium
Confined space hazards	15	Use smaller equipment, pre-lift planning	Very High
Weather conditions (wind gusts)	9	Suspend lift if wind exceeds threshold	Medium
Poor communication	9	Radios, standardized hand signals	High
Lack of emergency procedures	10	Develop and drill emergency plan	Medium

Table 11 Implementation Timeline

Phase	Activities	Duration	Responsible Party
Phase 1	Formation of Safety Committee, role assignment	1 week	Project Manager
Phase 2	Equipment audit, installation of monitoring systems	2 weeks	Safety Officer & Engineer
Phase 3	Training and certification of personnel	3 weeks	HR & Safety Officer
Phase 4	Lift Plan creation and digital permit implementation	1 week	Project Engineer
Phase 5	Daily operations with monitoring	Ongoing	All Personnel
Phase 6	Weekly and monthly audits, KPI evaluation	Ongoing	Safety Officer & Committee

regulations is heavily dependent on proper documentation. Overall, robust documentation and reporting systems strengthen risk management, support informed decision-making, and contribute to safer and more efficient lifting operations in metro construction projects.

3.10. Results and Discussion

The study on lifting operations in metro construction projects revealed a complex interplay of mechanical, human, environmental, and operational hazards. Site visits, interviews, incident analysis, and document reviews highlighted that while cranes and hoists were generally well-maintained, inconsistencies in rigging practices and deviations from lift plans were common, often caused by human error, site constraints, or environmental factors such as wind gusts. Human factors, including communication gaps, operator fatigue, and inconsistent supervision, significantly influenced risk levels. Environmental conditions, such as uneven terrain, ground stability, weather, and site congestion, also contributed to lifting hazards. A detailed hazard identification and risk analysis indicated that mechanical failures, improper rigging, and human errors were high-priority risks. Environmental hazards, site congestion, and complex lift sequences were moderate risks, while electrical hazards were low-probability but high-severity risks. Observed near-misses largely involved minor load misalignment, overstressed rigging, or miscommunication, underscoring the importance of preventive measures. Existing safety management practices showed strengths in lift planning, operator certification, and pre-lift inspections, but gaps existed in refresher training, real-time monitoring, and comprehensive documentation. Integration of load monitoring systems, digital permits, and GPS-based crane positioning was partially implemented, enhancing operational safety where applied. QA risk assessment matrix quantified hazards by likelihood and severity, prioritizing human error and mechanical failures. Findings indicate that effective safety management relies on:

- Standardized Lift Plans with risk matrices
- Competency-based training and supervision
- Pre-lift inspections and real-time monitoring
- Adoption of technology for hazard tracking
- Strong safety culture and continuous reporting

The discussion confirms that systematic safety management, combining technical controls, human-factor mitigation, and robust documentation, significantly reduces accident likelihood and severity. Continuous learning from incident data strengthens operational safety and aligns practices with ISO 45001 and OSHA standards, providing a model for risk-informed lifting operations in metro construction.

Conclusion

Lifting operations in metro construction are inherently high-risk, involving heavy loads, confined spaces, and complex urban site conditions. This study highlights that systematic risk assessment and structured safety management are essential to protect personnel, minimize incidents, and maintain operational efficiency. Key hazards identified include mechanical failures, human error, environmental challenges, operational constraints, and logistical complexities. Mechanical risks, such as crane overload and rigging failures, require preventive maintenance, regular inspections, and adherence to manufacturer guidelines, while human factors like operator competency, communication lapses, and fatigue demand targeted training, supervision, and fatigue management strategies. Environmental hazards, including wind, rain, and uneven terrain, underscore the need for real-time monitoring and adaptive lift planning. The research proposes a structured risk assessment framework that prioritizes hazards by likelihood and severity and integrates mitigation measures, including detailed Lift Plans, competency-based training, pre-lift inspections, and emergency protocols. Technology, such as load monitoring systems, digital permit-to-work platforms, and GPS-based crane positioning, enhances oversight, communication, and data-driven decision-making. Comprehensive documentation of lift plans, inspections, training, and incidents ensures regulatory compliance, accountability, and continuous improvement. Finally, fostering a proactive safety culture, where personnel are empowered to report hazards and adhere to safety

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protocols, is critical. The integration of technical, procedural, human, and technological strategies establishes a resilient safety management system. Implementing these practices significantly reduces accident risk, improves operational efficiency, and ensures the well-being of all personnel in metro construction projects.

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