

EFFECTIVE MEP COORDINATION AND RISK MITIGATION USING TOTAL PROJECT MANAGEMENT PRINCIPLES, RISK BREAKDOWN STRUCTURE & PROBABILITY IMPACT

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Abstract

The execution of Engineering, Procurement, and Construction (EPC) based projects entails the involvement of multiple stakeholders focusing on achieving cost, time and quality objectives. Pre-defined Key Performance Indicators (KPIs) are established to facilitate the client Hand Over Take Over (HOTO) process for successful completion of such projects. This study proposes the implementation of a Design and Data Management System (DDMS) for effective Mechanical, Electrical and Plumbing (MEP) coordination and methods to attain the predefined KPIs. The building industry in Pakistan has been persistently failing to meet these KPIs, leading to compromises in Health, Safety, and Environment (HSE), cost, time schedule and sustainability. This study aims to address these challenges during the DDMS cycle by proposing a coordinated risk management approach that involves methods to identify, evaluate, and manage risks while ensuring effective communication among all stakeholders involved in the project. The research identifies limitations in the existing DDMS and proposes a new Project Management System (PMS) model in Pakistan. It analyses the impacts of the proposed PMS model on the KPIs, comparing the effects, with and without MEP coordination and risk assessment. The research emphasizes the need for an efficient and robust PMS for the successful execution and sustainability of infrastructure projects in Pakistan.

INTRODUCTION

MEP Coordination in Infrastructure Projects

Efficient coordination of MEP services diverse components is crucial to ensure the certainty of execution. Incompatibilities across systems can cause conflicts during site works, leading to unavoidable delays. Execution of complex projects with multiple MEP systems requirement

cannot commence until the coordination issues are addressed and resolved. DDMS encompasses not only the layouts, volumetric play, and exteriors of infrastructure projects but also the complete package of structure, civil and MEP [1]. The coordination of all MEP assets is critical in achieving the KPIs and reducing construction and

maintenance costs through an iterative process that integrates proper DDMS with mock-ups. Effective MEP coordination is essential for sustainable outcomes where cost, quality, and time impacts are closely intertwined. Neglecting MEP coordination during the evolution and execution of the project can lead to the infrastructure becoming a white elephant.

Approximately 40% of a building's DDMS and budget is allocated to effective MEP services [2]. Therefore, giving due regard to these processes is critical to ensure sustainability of the project with minimal Operation and Maintenance (O&M) costs [3]. Figure 1 shows the control points where MEP coordination is necessary during the project life cycle.

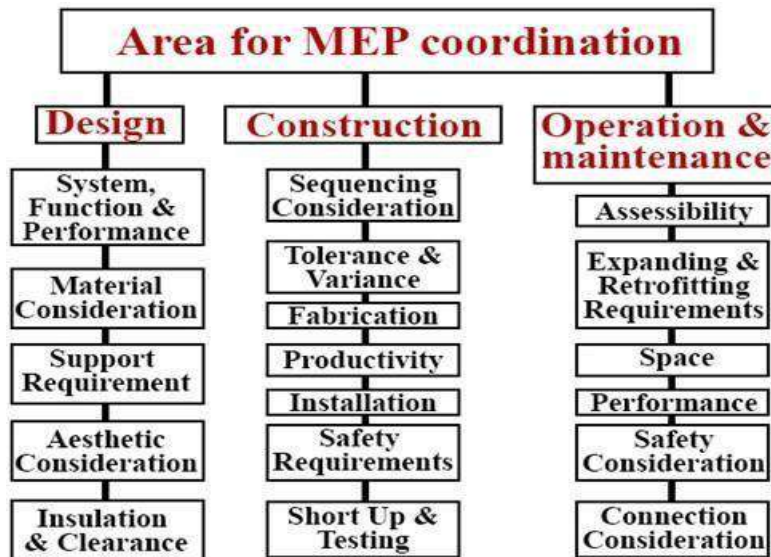


Figure 1: Area for MEP Coordination

PMS in Pakistan

In Pakistan, Scope of Works (SoW) is typically followed by a Need Assessment Report (NAR) and engagement of a consultant. However, consultants may lack the necessary Research and Development (RD) skills and expertise, leading to issues with the Project Charter 1 (PC-1) preparation [4]. Additionally, town planners and architects, who are not necessarily engineers, may overlook MEP and other technical issues during the design process during the preliminary and design phases resulting in cost and time overruns, as well as HSE and quality issues. MEP services of the infrastructure are typically integrated during the execution phase, when preparing the shop is a major part of construction management as one impact may cause changes in other. The relation between the performance criteria and

drawings. However, this process is often deficient in the stakeholder management. Architects and engineers do not coordinate effectively and frequently, leading to negative impacts on the project compromising value engineering and sustainability.

KPIs of MEP Coordination

Proper coordination of the MEP systems at all phases of a project in a standardized manner can reduce the time delays during the construction phase by 50% [5]. This coordinated approach can also result in a decrease of 20-40% in the OM costs of the project [6]. The continuous involvement of all the project heads unit of analysis of MEP coordination is shown in table.

Table 1: Key Performance Indicators (KPIs) of MEP Coordination

KPI	Description
Time	Duration for MEP coordination processes from design to installation.
Cost	It measures the financial aspect including the cost of design changes and construction delays caused by coordination issues.
Sustainability	It measures the environmental impact including energy efficiency, carbon footprint, resource consumption.
O&M cost	It measures the long-term cost of operating and maintaining the MEP systems (energy efficiency, maintenance requirements, and equipment lifespan) after the construction project is completed.
HSE	It measures the safety (fire safety, ventilation, and water quality) for the occupants of the building and the general public.

Risk Analysis

MEP coordination requires risk assessment at all phases of the project management. This process should be initiated from the preliminary phases to the post design phase, known as the HAZOPS (Hazard and Operability Study). All execution phases shall require Job Safety and Environmental Analysis (JSEA) with coordinated shop drawings from the contractor. This is followed by HAZIDS (Hazard Identification) for the asset management purpose that assists the managers to run and maintain the project effectively.

DDMS

Construction planning often does not devote sufficient time and resources to the coordinating process in Pakistan. Infrastructure projects are largely driven by their design and drawings including all MEP plans. These drawings should be coordinated properly with all the project heads for conveying the construction notes to compliment the ground reality along with other installation details [7]. Figure 2 shows the major steps of DDMS. The sub components of these steps should be followed in all construction and infrastructure projects for their success and sustainability.

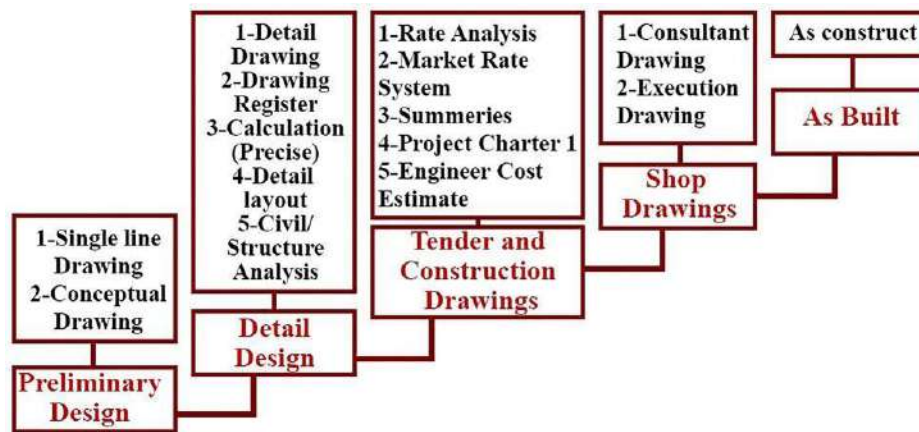


Figure 2: Steps of DDMS

Preliminary Design

The preliminary drawings of a project are developed at the feasibility phase. These are basically conceptual drawings that should not be

followed in the construction phase. They only represent early planning [7]. In Pakistan, these conceptual plans are missing from the DDMS altogether. Consultants often jump to detail design without

giving due regard to the standards, budgets and MEP coordination.

Detail Design

Detail Design drawings are developed based on the concepts, schemes and standards decided and agreed upon in the preliminary design. These must be prepared by a recognized consultancy where a team of professionals related to all the fields should focus on details, such as calculations, surveys, reports. MEP coordination is needed during the design process for any conflict management and preparation of accurate engineering estimates with full technical and equipment specifications [7].

Construction and Shop Drawings

The construction drawings are the actual project design to be implemented during the execution phase. The shop drawings provided by the MEP vendors in Pakistan are generally not properly coordinated with the construction design provided by the consultants. This should be a sole responsibility of the contractor, which they often fail to fulfill. These drawings should provide all the information of the project, graphic or written [7].

As Built Drawings

Coordinated As-Built with site mock-ups must be provided by the contractor after the complete execution and HOTO of the projects. These drawings should also be coordinated with the O&M manuals of the MEP assets [7].

C. Problem Statement

The problem addressed in this project is the lack of effective coordination and integration of MEP systems in the construction and infrastructure projects in Pakistan, leading to cost overruns, extended timeline, and unsustainability of the projects.

D. Research Objectives

To integrate a coordinated MEP model with risk assessment, a comprehensive analysis of a significant infrastructure project in Pakistan is conducted across multiple phases of the project. This study assesses the impact of MEP

coordination on the estimated versus actual cost and time impacts of the project. The investigation will also determine the impact on cost due to the absence of MEP coordination to support the analysis. The analysis will contribute to the development of best practices for MEP coordination and risk management in construction projects in Pakistan. The findings also provide insight for stakeholders, including project managers, engineers, and contractors, on the importance of effective MEP coordination to meet the project KPIs.

LITERATURE REVIEW

Pakistan's construction techniques are very ad hoc hence the coordination of the MEP systems becomes the most challenging task in an infrastructure project. The MEP system plays a vital role in the sustainability and functionality of buildings and infrastructure projects. According to Akadiri et al. [8], the MEP system is a crucial part of the building, and its proper functioning is necessary for the comfort and safety of occupants. Several studies have emphasized the importance of proper coordination and integration of the MEP system in infrastructure projects. For instance, Yehia et al. [9] investigated the impact of poor coordination on the MEP systems in a hospital project and found that it resulted in significant delays and cost overruns. Similarly, Hassanain et al. [10] conducted a study on the coordination of MEP services in construction projects and concluded that the lack of coordination among the services can lead to delays and rework. According to Carli et al. [11], the MEP system is responsible for the majority of energy consumption in buildings, and therefore, its proper design and coordination can lead to significant energy savings. MEP systems with other building systems presents additional challenges, particularly during the construction phase when they must be installed in constrained spaces while adhering to standards of constructability, operability, and maintainability [12]. The proportion of the overall building project budget allocated to installing the MEP systems varies depending on the scale and complexity of the project, ranging from 15% to 60% [13]. A

structured framework has been introduced by Wang and Leite [14] for capturing knowledge

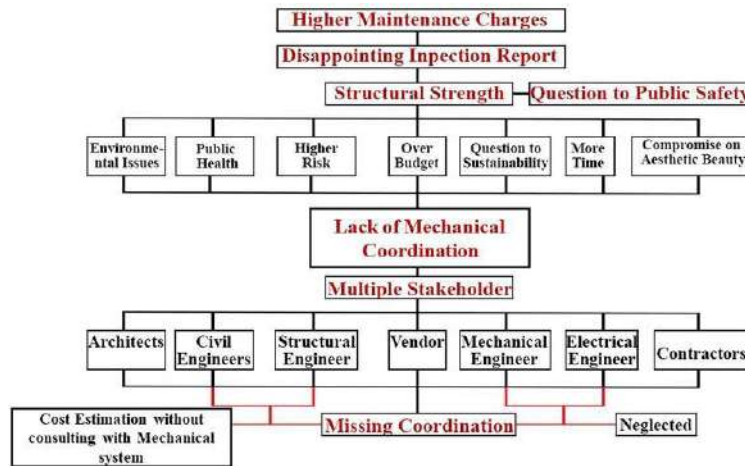


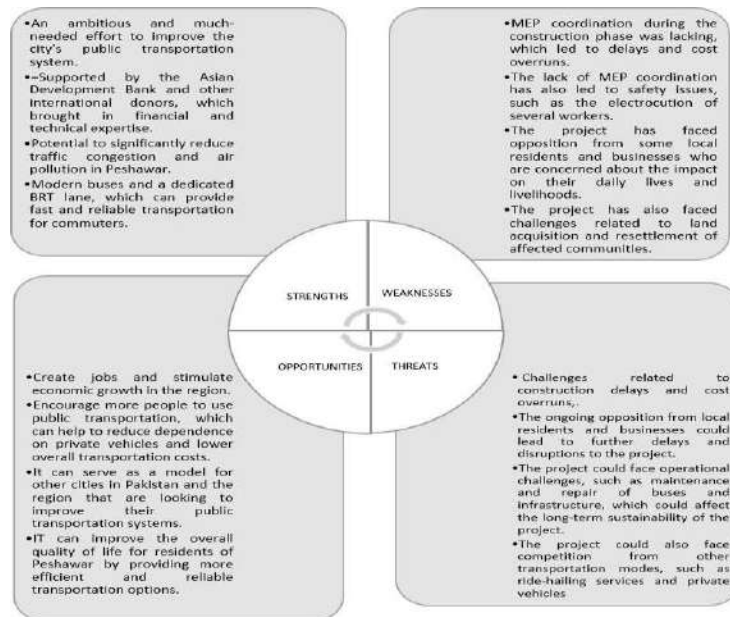
Figure 3: Problem Tree of Neglected MEP Coordination

related to design coordination. Lee et al. [15], analyzed the impact of implementing different MEP coordination strategies on productivity at the execution phase. A systematically devised Building Information Modeling (BIM) strategy has been implemented with the aim of improving productivity. This involves the creation of a rule-based automated engine for MEP tasks using the Revit API[16]. A Khanzode [17] demonstrated the coordination of MEP systems in a hospital project through the utilization of BIM and Virtual Design and Construction (VDC) tools.

METHODOLOGY

The study aims to identify the missing phases and steps in DDMS and analyze their cost, time, and sustainability. The methodology employed in this research involves a systematic approach to risk mitigation. The study intends to identify and mitigate the risks associated with an uncoordinated MEP system and incorporate a risk management system to ensure effective DDMS practices. Figure ?? illustrates how the inclusion of risk analysis following DDMS can influence the risk factor and percentage loss.

SWOT Analysis



POTENTIAL RISKS OF THE PROJECT

It was concluded that there was no coordinated detail engineering design in place when the contractor was mobilized, due to poor DDMS issues. This lack of planning and coordination resulted in the project design being based solely on the pre-feasibility report, leading to further problems down the line. Additionally, the revised PCI was completed in November 2017, but the assigned consultant continued changing the design, resulting in variations, indicating a lack of coordination, competency, and management issues. The MEP design, specifically the Heating, Ventilation and Air Conditioning (HVAC) had plenty of standardization issues due to poor design management. Furthermore, after the execution, it was observed that the BRT route should have been somehow elevated to avoid traffic congestion for now and in the future, and there was no drainage facility provided at the elevated portion of the BRT. Moreover, no

pedestrian crossings, other than the BRT bus station approaches, were provided, and the washrooms at the BRT stations were constructed with improper foundations, without lintel and using poor quality bricks. The bike lane was not maintained throughout the BRT route; it was eliminated at some locations, while at others, it was combined with mixed traffic lanes. The concrete work was also designed to be carried out as panels, but the execution resulted in 40 m long concrete blocks which caused cracks as the work proceeded. Finally, the Peshawar Development Authority (PDA) failed to provide details as per FIDIC, further compounding the MEP coordination issues in the construction phase of BRT Peshawar. Using the identified factors, an analysis is conducted to assess the potential risks associated with the project. The aim of this analysis is to determine the likelihood and impact of each individual risk.

Table 2: Risk Register of the Project

Major Risks	Risk Owner	Cause	Effect	Probability	Level of Risk
Cost Constraint					
Major Risks	Risk Owner	Cause	Effect	Probability	Level of Risk
R-3 Optimal performance issues	Engineers	Lack of coordination	Significant increase in energy consumption and O&M costs	60-80%	HIGH
R-4 Design and installation errors	Engineers, Contractor	Lack of coordination	Error verification processes increase costs	30-70%	HIGH
Time Risk					
R-5 Re-work and revisions	Engineer, Contractor	Lack of coordination	Duplicate design errors cause time constraints during construction	40-70%	HIGH
Sustainability					
R-6 Poor quality	Contractor	Poor quality of work	Not meeting required standards; rejections by QC teams	40-60%	MEDIUM
Health and Safety Risk					
R-7 Accidents, injuries, fatalities	-	MEP coordination after project completion	Exposed MEP assets	40-60%	MEDIUM
O&M Risk					
R-8 High O&M cost	-	Lack of coordination in work	Budget blowouts	60-80%	HIGH
R-1 Delay in construction schedule	Contractor	Lack of coordination	Conflicts and clashes between MEP and other construction teams	70-90%	HIGH
R-2 Change in SOW	Investor	Lack of satisfaction with the design and ongoing work	Disturbance in design and process	5-40%	MEDIUM

IMPACT STATEMENT

Based on the risk prioritization matrix, it has been determined that time and cost risks remain significant for every probability. These anticipated

risks could have been mitigated if addressed in the initial phases of the project. Therefore, a proper DDMS model will be presented to

Probability of Risks	Impact		
	High	Medium	Low
R-1	Red	Red	Yellow
R-2	Yellow	Yellow	Green
R-3	Red	Red	Red
R-4	Red	Yellow	Green
R-5	Red	Red	Red
R-6	Yellow	Yellow	Green
R-7	Yellow	Green	Green
R-8	Red	Yellow	Green

Figure 4: Risk Assessment Matrix (Probability vs impact)

illustrate the impact of using risk reduction techniques in the project.

Through the use of a formal and professional tone, this paragraph emphasizes the importance of identifying and addressing risks early on in the project to mitigate their impact. The DDMS model will serve as a tool to demonstrate how implementing risk reduction techniques can help to minimize the impact of potential risks on project timelines and costs.

Social, HSE Impacts

BRT Peshawar missed nearly all its KPI thus creating an environmental disaster. Debris everywhere created havoc for commuters. The project is in a densely populated area with a high volume of residents, pedestrians, and traffic. The risk of accidents, HSE issues, longer and stressful commuting time, traffic jams, broken and uneven roads, carbon emissions causing extreme air pollution, and the list goes on. If the project had been planned and coordinated properly by

conducting a proper risk assessment and TPM model, this would have been avoided, resulting in a sustainable infrastructure for the city.

Financial Impacts

This cost is more than the cost of infrastructure of Lahore and Islamabad Transit Systems that is \$45M and \$27M USD respectively. The government took a loan of \$335 million from the ADB (Asian Development Bank) for a period of 25 years. The other loan of \$75M USD (PKR. 1162M) was granted by the Agence Française de Développement (AFD) and European Investment Bank (EIB) for civil works. The total cost till September 2019 is PKR 71 billion. The chunk of the cost impacts and variations were due to the uncoordinated MEP and BS systems, as well as the neglected risk assessment procedures. The inspection, audits, and progress reports done during the execution phase of the project identified various issues.

This research shows that the cost of the BRT Peshawar project would have been significantly lower if a coordinated TPM model was followed. The construction cost of the project would have been \$428.5M USD (PKR. 71,323.8M), which is three-fourths of the costs utilized till now, along with O&M and asset management cost impacts.

Environmental Impacts

Ambient air quality parameters should be within the acceptable NEQS guidelines; however, additional emissions arose during the construction phase due to delays and additional use of construction equipment. Noise impacts in the immediate vicinity of the project corridor also affected the quality of life. Wastewater and fuel spills from staff and labor camps did not have any proper public health integration. The storm water run-off from the construction site was contaminated, reducing soil quality.

The absence of national or domestic regulations and a waste management system has the potential to cause serious HSE issues, particularly with local contractors. Although it is expected that the BRT Peshawar project will help improve the

environment, promote cheap and comfortable means of travel, and open job opportunities, the removal of hundreds of trees, destruction of green belts, increased dust, and associated discomforts cannot be ignored. Lack of MEP and BS coordination and weak TPM practices led to these KPI blowouts.

Incorporating DDMS

The efficiency of a construction workflow is optimized when tasks are carried out in a methodical and uninterrupted manner. In the event of a disagreement arising from MEP coordination, it is often too late to proceed without interruption until the matter is resolved. When a team is forced to halt work to relocate, wait for information, or wait for supplies, productivity declines. The situation is further compounded when subsequent crews and operations encounter the same issues.

The expenses incurred as a result of these disputes, as well as the extent to which other crews are affected, vary depending on the complexity of the project

Table 3: BRT, Peshawar: Phases and Descriptions

Sr. No.	Phase	Description
DD-1	Preliminary Phase	The feasibility was performed by incompetent stakeholders, which failed to coordinate even simple parameters like the route length. A well-coordinated effort by the concerned department would have resolved most of this issue at the preliminary phase.
DD-2	Design Phase	A standardized detail design with proper parameters and integration of design and construction codes is the best practice at this phase. The research concluded that no design specifications were followed, the consultants failed to show any due diligence. Poor or outdated design, over-engineering and no concept of mock-ups was integrated, leading to excessive variations at the execution phase.

DD-3	Estimation Phase	PC-I was developed by using the MRS-2016 while MRS-2017 was approved, causing huge cost blunders. This could have been avoided by using proper estimation standards and getting all rate analysis reviewed and coordinated.
Sr. No.	Phase	Description
DD-4	Tendering Phase	The General and Specific Conditions of Contract (GCC and SCC) were poorly laid out, FIDIC and PPRA clauses were completely ignored by the stakeholders. Contractual issues can be easily rectified by involving the relevant approving authorities during the feasibility and the design phases.
DD-5	IFC Phase	The execution initiated way before the Issue for Construction (IFC) package was issued to the contractors leaving many stakeholders clueless. The proposed DDMS model can easily rectify this issue on any mega project by ensuring a systematic drawing management system for the TPM life cycle.
DD-6	HOTO Phase	The punch-lists on the project are not coordinated. This followed by a weak Inspection and Testing Plan (ITP) caused unnecessary delays and variations. A proper DDMS will allow easy coordination for HOTO of any mega projects.
DD-7	O&M Phase	At O&M phase, proper human resource with Safe Work Methods Statements (SWMS), who are properly trained, have the right experience and certifications should be integrated on the project. Since BRT-Peshawar has not entered this phase yet, it is important to note that right steps at this stage for the compilation of manuals, GIS and "As-Builts" of the site can only assist in effective asset management of the site. Regular JSEA must be carried out to make projects sustainable.

This phased approach model will increase the project life cycle and sustainability by decreasing the probability of risks occurrence. It will also shield the project from any unwanted challenges during the construction and the O&M phase. Table 4 clearly shows that the risks are signifi-

cantly reduced after carrying out a coordinated MEP with risk assessment model.

Table 4: Risk Factor, Probability of Occurrence of any Risk in Different Phases

Phase		Before			After		
		P	I	Risk	P	I	Risk
C & M - 1	Preliminary Design	2	3	6	2	1	2
C & M - 2	Detail Design	1	3	3	1	1	1
C & M - 3	Estimation	1	3	3	1	1	1
C & M - 4	Tendering	3	1	3	3	1	3
C & M - 5	Issued for Construction	2	1	2	2	1	2
C & M - 7	Hand Over Take Over	3	3	9	3	1	3
C & M - 8	Operation and Maintenance	2	2	4	2	1	2

NEED OF MEP COORDINATION

Upon completion of the grey structure of a building, the MEP fittings are often given minimal consideration, with shop drawings serving as the primary basis for installation. Unfortunately, site mock-ups are seldom prepared, and infrastructure-related systems such as Dial Before You Dig (DBYD) are non-existent. Consequently, the infrastructure's aesthetic appeal is negatively affected, and construction and operational costs are significantly increased. To address the issue of high resource utilization, the underlying cause must be eliminated. Figure ?? depicts the causal relationship between neglected MEP coordination and project inefficiencies. Furthermore, the lack of coordination of MEP and BS during the preliminary and design phases can complicate the execution, completion, and implementation of design within the Building Information System (BIS). Non-standardized and uncoordinated design can lead to Occupational Health and Safety (OH&S) concerns, public health risks, procurement challenges, and environmental issues. To mitigate these problems and overcome project bottlenecks, BS coordination must be

integrated from the preliminary phases up to the Handover Takeover (HOTO) phase. This approach will result in a standardized project design with a solid foundation that complies with the Lowest Price and Technically Acceptable (LCTA) principles.

Conclusion

The case study of BRT Peshawar is analyzed in the research to offer guidance on incorporating risk assessment as a critical component of project feasibility assessment. Specifically, it emphasizes the importance of ensuring MEP coordination during project execution and mitigating future risks through early identification. Through a detailed review of the BRT Peshawar project, potential risks have been identified that could have been mitigated if a preliminary risk assessment had been conducted during the initial stages. This highlights the necessity of conducting a preliminary risk assessment to prevent potential risks from materializing during later stages of the project, thus reducing their potential impact. Furthermore, the study identifies critical factors that can impact a project's KPIs, such as cost, time, quality, sustainability and HSE considerations.

Authors' Contributions

Dr. Engr. Anser Kazim: Provided overall supervision, conceptualized the research idea, and reviewed the final manuscript.

Engr. Nasir Abbas: Developed the methodology, performed technical coordination reviews, and contributed to analysis and validation of findings.

Engr. Asad Ali: Collected project data, prepared MEP coordination documentation, and drafted the initial version of the manuscript.

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