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INVESTIGATION ON IMPACT OF REWORK DURING INSTALLATION OF MECHANICAL, ELECTRICAL AND PLUMBING (MEP) SYSTEM AT METRO STATIONS IN SAUDI ARABIA

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ABSTRACT

Mechanical, Electrical and Plumbing (MEP) system is lifeblood of any building which increase the building value and functionality. For instance, you are in the most magnificent building of the city, if air conditioning and lights are taken away you will be left in a dark and suffocated shell. Similarly, modern services increased the complexities in construction and reworks during MEP installation has become an acceptable characteristic which causes quality deviation, cost overrun and time delay. This research aims to identify rework in installation of MEP system and its impact on project performance. This case study was conducted in three main stations of Riyadh Metro Project (RMP) in Saudi Arabia. By applying quantitative method total 130 construction professionals were selected from client, consultant, contractor and sub-contractor companies. Before submission of final survey pilot testing was conducted to verify feasibility of questionnaires using Cronbach's alpha (α). Data examined in Statistical Product and Service Solution (SPSS) and research result revealed the potential causes of rework that impact on project quality, cost and time. The results also indicated that impact of reworks in terms of project performance is higher on quality than time and cost. The mitigation strategies to avoid reworking such as; improved coordination among disciplines, allocation of qualified MEP engineers, deployment of skilled workers, use of approved design at installation and timely submission of quality inspection request to QC engineer were ranked higher by construction experts. Finally, the research concluded potential strategies as a pathway to help construction professionals to prevent rework and enhance performance of future building projects.

Keywords: Mechanical, Electrical and Plumbing (MEP), Rework, construction, metro projects.

1. INTRODUCTION

In the world of construction MEP stands for Mechanical, Electrical and Plumbing [1]. MEP system is also known as Building Services System (BSS) it turns the building from empty rooms into comfortable spaces that will be friendly and liveable for the residents. In building projects the MEP system plays a significant role as the blood, nerves and digestive system in the human body [2].

In mega building projects MEP system installation takes 40-50% of total construction time [3]. Moreover, the time required to complete MEP testing in industrial building reached to 26 % of project total duration [4]. In modern building projects the cost of MEP has reached to 25-40% of the project total cost [5]. The percentage of cost and time is increasing frequently due to advancements in building technology and services.

MEP system is complex in design and requires specialities for design and installation at site to avoid reworks. Fixing of defective components which discovered during testing results 12% cost of respective system installation [6]. Usually, in design stage architecture and structure drawings are developed first and due to deficiency of MEP knowledge structure engineers and architects left limited space for MEP equipment and services [7]. Rework is one of the main reasons for time and cost overruns that impact the project success.

Therefore, the Engineering Procurement and Construction (EPC) industry facing challenges in delivering building projects on time and within a budget [8]. The performance of construction projects can be elevated with the implementation of rework moderation strategies [9]. Considering the necessity for construction professionals to mitigate reworks by transformation of tacit information from the construction field to the body of knowledge. The current study has been carried out to demonstrate the possibility of reducing reworks resulting from MEP installation during the construction phase of the RMP. A case study conducted in three main stations 1A1, 1B3 and 1F7 of line-1 in RMP.

2. LITERATURE REVIEW

In 21st century buildings are becoming more complex and the complication rising each year due to new technologies and increasing demands of building owners [10]. The MEP system become an essential discipline in construction projects. MEP system consists of several sub-systems integrated together which alters the building into a comfortable, friendly and safe place for its residents [11].

2.1 APPLICATION OF MEP SYSTEM IN CONSTRUCTION PROJECTS

The construction industry is divided into five different divisions. This distinction is based on the nature and application of project [12]. The five common divisions of construction projects are:

i. Residential Building Construction

ii. Commercial Building Construction

iii. Infrastructure and heavy construction

iv. Industrial Building Construction

v. Institutional Building Construction

Every building consists of MEP services and without it the building is like a human without skeleton system. Whether in a multi-story building, healthcare facility, institutional building, or a metro station the MEP system transforms buildings from empty rooms into comfortable space [13]. MEP system is mandatory in residential, commercial, industrial and institutional buildings, in modern building projects MEP system make them more attractive living spaces for building residents [14]. The fundamental application of MEP sub-systems in buildings project are air conditioning, water supply, power supply, lighting, fire protection and alarm, drainage and sewage services and building management system etc. [2].

2.2 REVIEW OF MEP SYSTEM IN RIYADH METRO STATIONS

According to General Authority for Statistics (2018) Riyadh is the biggest city in Saudi Arabia and one of the largest cities in the Middle East with a population of around 7.6 million and expected to grow up to 10 million by the year 2025. Considering the growth in population and traffic Saudi Arabian government has invested more than 26 billion US$ to build the largest urban transit system in capital city of Riyadh. The metro project is under construction since from April 2014 and is expected to be operational in the coming years [15] the revised plan for completion is in 2024.

The experts in public transportation around the world are interested to improve the service quality of transportation [16]. In contrast to conventional building projects, the design life of RMP assumed as 100 years and accordingly the metro stations are fully furnished with modern MEP system to accommodate the future population. The research area included three main transfer stations of line 1 at RMP named 1A1, 1B3 and 1F7. Typical scope of the MEP services is almost uniform in main stations but some of the sub-systems differ conditionally due to limitations of the space in false ceiling; such as ducts, pipes and equipment clearance in iconic stations. Figure 2.1 shows the MEP sub-systems classification applied in main stations of RMP.

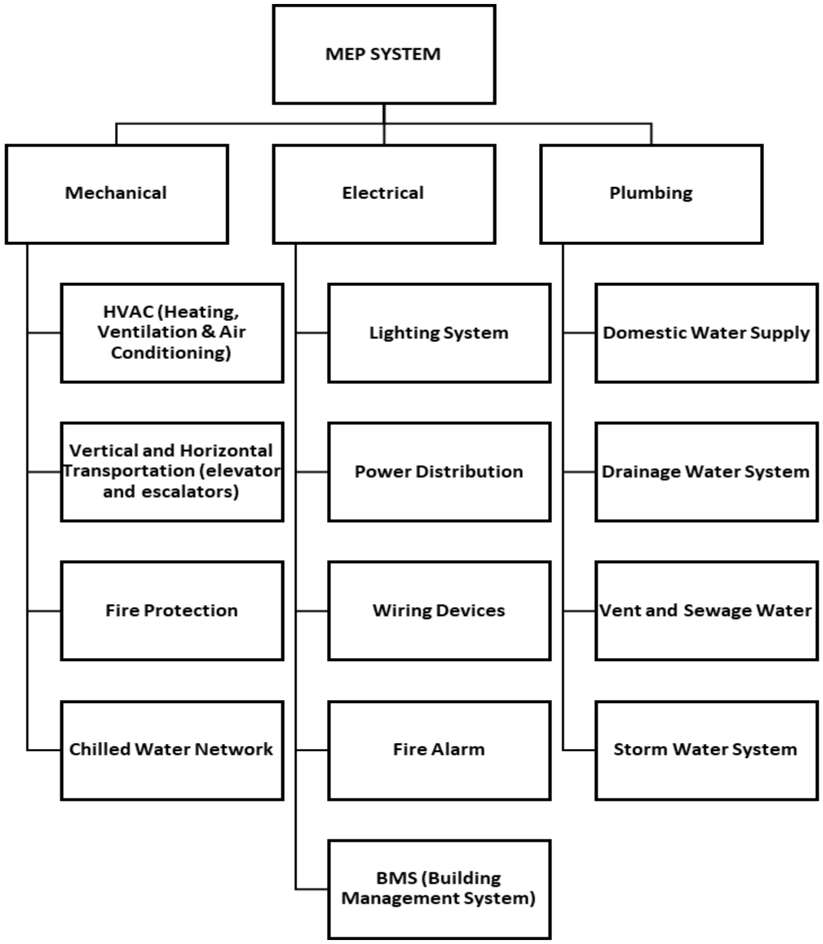


Figure 2.1: Classification of MEP system and sub-systems

2.2.1 Mechanical System

Mechanical is considered as the heart of MEP system. In mega project mechanical system reached up to 60% of total MEP scope. One of the fundamental part of mechanical is HVAC (Heating ventilation Air Conditioning) accountable for controlling indoor environment [17]. Buildings use many types of mechanical sub-systems but major part of mechanical work in residential and commercial buildings deal with HVAC. The space heating, ventilation and air conditioning systems maintains desired environmental conditions inside buildings.

Building temperature, humidity and ventilation control systems are designed and installed by mechanical engineers. In metro stations of RMP every floor holds mechanical rooms and shafts which are designated for equipment such as FCU (Fan Coil Units), AHU's (Air Handling Unit), Pumps, elevators, escalators and mechanical piping. The chillers are installed in cooling yard on roof levels of stations kept open to sky as per recommendation of manufacturer to enhance efficiency of the plant. The exposed to public parts of mechanical in stations are fire hose cabinet, sprinklers, grills and diffusers [4].

2.2.2 Electrical System

Electrical is also one of the core segments of MEP engineering. Electric current is essential for building services like blood for the human body [2]. The main equipment of electrical system in buildings are panels, containments (conduits, cable trays and ladders), lighting fixtures, switches and sockets, power distribution boards, wiring devices and earthing protection[18]. The large scale and mega projects like metro stations mostly designed and installed according to international electrical codes and standards to meet customer satisfaction [19].

In RMP the design and installation of electrical systems applied based on local and international codes as per employer requirements. The electrical devices installed in metro stations for smooth operation of the facility [20] the electrical system consists of various logical equipment connected by various size cables and wires for flow of current and feed lights and equipment for successive operation of rapid transit.

2.2.3 Plumbing System

In buildings projects plumbing system is responsible for distribution, storage and pumping cold and hot water from reservoirs to plumbing fixtures through pipes [21]. According to research buildings consume 25% of global water and 40% of global resources [22]. Thus plumbing system for effective management of water in buildings is an important sub-system of MEP to reduce global waste and increase recycling to achieve UN sustainable development goals (SDG).

In DUS (Deep Underground Station) plumbing becomes more challenging especially when it comes to drain and supply water from 45m deep underground platforms and pits of train tunnels. Building sewerage consists of plumbing fixtures; soil, waste and vent pipes with combination of floor drains, scupper drains and cleanout plugs on floor and roof for collection of storm water by horizontal and riser pipes. The local building codes (or Saudi Building Codes) provided specifications for design and installation of plumbing system according to weather parameters of Riyadh city.

2.3 MEP SYSTEM ASSOCIATED REWORKS IN CONSTRUCTION

Due to several challenges the building construction sector is facing poor performance in terms of schedule, cost and quality [23]. During construction several problems in MEP system installation affect project performance. Many MEP services in building projects passes from concrete shafts or fit-in ceilings and shafts space kept by architectural and structural designs. Hence spaces are often restricted in size due to a lack of MEP system awareness by various disciplines.

The limited spaces cause MEP system installation and testing issues. The involvement of MEP engineers in early design may prevent such issues and will allow smooth installation of system in the facility during the life cycle of the project [10]. Various factors have the potential to interrupt construction site work progress and to impact workers productivity but rework impact project performance with high magnitude [24].

Most building projects are exposed to high risk due to structural complexity and application of latest MEP systems. The complication of work due to HVAC, fire alarm, drainage, elevators, fire protection and clean agents, power and lighting in rooms as per client increasing with time. Many mitigation strategies were explored for smooth construction to avoid reworks which will manage costs over runs and time delay issues in projects [25].

Building information modelling (BIM) has found one of the approaches which have demonstrated its advantages in improving mechanical, electrical and plumbing (MEP) layout in the design stage. Unfortunately, BIM applications normally stop prior to construction stage and MEP layout design may no longer fit properly during the installation process when there are as-built deviations between structures and MEP installation while execution at field [26].

Large scale construction projects still have issues for supporting cooperative construction management due to generation gap between construction industry and modern technology which cause issues for installation of services and affect the project management at site [27].

2.3.1 Rework identification

Rework is one of the most common problems in construction. The rework definition has been elaborated by many researchers such as; “non-conformance”, “deviation” and “quality failure”. Rework is unnecessary effort of re-doing a process or activity which incorrectly completed for the first time [28]. According to the Construction Industry Institute (CII 2001) rework is described as activity at site that performed more than once or an activity that eliminate the earlier installation in the field [29].

According to International Journal of Sustainable Construction Engineering & Technology (IJSCET) published by Universiti Tun Hussein Onn Malaysia (UTHM) rework is process in which an item get approve as per requirements by additional efforts after completion more than once due to non-conformance with quality standards [30]. Rework is modifying the product according to the customer or engineer's specifications when the product or service does not meet customer requirements. Therefore, the rework contributes to waste and value losses in building design and construction [29].

2.3.2 Causes of rework

The construction industry in general is still struggling with inefficiency issues in the implementation of its construction procedures. Rework and causes differ in construction due to unique nature of each project's budget, schedule and availability of resources [31]. Rework can mainly result from four primary sources like error, omission, change and damage during the design and construction [29]. Some of the factors related to reworks identified by researchers during installation of the MEP system are listed below:

i. Inadequate experience of MEP system installation

ii. Poor coordination between design and construction

iii. Lack of coordination between interlinked disciplines

iv. Delay in approval of design

v. Material size and delivery issues

vi. Change of site condition

vii. Failure in installation and construction supervision

viii. MEP installation damaged by civil works

ix. Cash flow issues in the project

x. Lack of workmanship

xi. Disregard the sequence of construction

Several issues become root cause of reworks in construction stage of projects [32]. Any rework cause arises at initiation phase will continues through project stages until it reaches to final testing [33]. The cause and effect (Fishbone) diagram in Figure 2.2 shown the common rework causes.

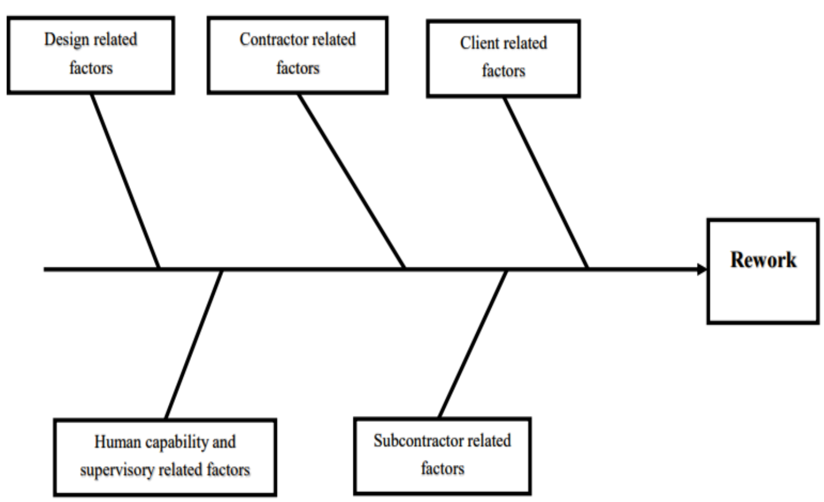


Figure 2.2: Fishbone diagram of rework root causes [33]

Moreover, some frequent rework causes observed during installation of the MEP system in Riyadh metro stations were; work resume prior to the approved drawings, shortage of skilled workers and qualified MEP engineers, failure to protect the completed works, delays in submission of inspection requests for work approval, change in design due to clashing with MEP services installation, lack of collaboration between equipment manufacturer and design selection, insufficient MEP qualified managers and engineers, communication and coordination issues among various disciplines, construction planning issues and unfeasible site condition for installation of MEP system.

To maintain the project acceptable performance it is not only be constructed as per specified quality but also to be delivered within specific time and cost [33] which can be achieved by lowering the causes of reworks by identifying them in the initial stage.

2.4 IMPACT OF REWORKS ON PROJECT PERFORMANCE

Rework is a global problem in construction industry. To conquer this matter a collective effort from construction professionals from industry is required to mitigate its adverse consequences [34]. Rework in construction projects has both direct and indirect impacts on project performance [33]. The rework accounted for around 4.4% percent of the overall project cost and required an additional 7% of total project time [35]. In addition, the direct effects in terms of time, cost and quality on specific activities, the rework occurrences often have indirect effects such as stress, loss of trust, low profit and de-motivation on individual or group.

2.4.1 Impact of rework on cost

Serval studies have investigated the cost of rework in the construction industry. According to Construction Industry Institute CII (2015) rework accounts for up to 20% of project total cost. The rework for industrial, residential and commercial buildings range from 2% to 6% from the contract value [36] also the major factors contributing to project cost overruns is rework [37]. The cost overrun is a regular incident associated with almost every type of construction project [33].

In construction the costs reduction which involve during the design and planning stage prior to the project execution. There is a strong positive and significant relationship between the cost of rework and the project cost and has substantial relationships between the costs of rework and project completion time [38]. Research conducted in Pakistan explored that average cost of rework in building project reached up to 5% of the contracts total cost [39]. Moreover, a study conducted on building projects in Malaysia revealed that the cost of rework normal ranged from 3-6% of the project cost and the performance impact due to rework reached from 5-10% for mega projects in Malaysian construction industry [40].

2.4.2 Impact of rework on time

Productivity of construction projects is regarded as one of the frequently discussed topics in construction industry [24]. Hence, time delay in construction industry is an old issue that impact the image of whole industry [41]. The construction industry is struggling with project management issues and the most notable of which are schedule delays which can be caused by number of variables including reworks [42]. Rework leads to a significant delay in project time according to a study by considering random projects executed in the last 20 years most of the project were delivered late, means schedule delays occurred in all projects [43].

The research published in IJSCET published in UTHM Malaysia time and cost overrun are linked which causing time delay issues in most circumstances [44]. Another study found out that rework increases the cost by 3-5% and schedule delay by 10–70% for different work categories for a residential and commercial project in Saudi Arabia [45]. MEP system installation rework begins during the execution stage of building projects and if not swiftly corrected may progress to the testing stage and finally it will impact the project delivery schedule.

2.4.3 Impact of rework on quality

Reworks and quality performance has a cooperative relationship. Poor quality occurs in more than 80% of building projects [46]. Effective quality significantly increases the project performance and aids in completion the project on time and equally effect the budget which is directly related to rework at project site. According to International Federation of Consulting Engineers (IFCE) any lack of quality in construction is arrive due to poor or non-sustainable workmanship later this creates reworks in the project.

Researcher asserted that to improve quality there is a need to understand the root causes of reworks. The basic reason for its existence or the set of conditions that stimulate its occurrence [33]. Several studies have consistently established that design and engineering stage of a project rework or quality issues emerge and impact project performance [47]. MEP system is a dynamic system which continuously operate after installation if reworks have identified in design and installation stage the project quality failure will also impact the maintenance performance in life cycle of project.

3. RESEARCH METHODOLOGY

The quantitative technique was applied in this research which comprised distributing well-structured self-explanatory questionnaires to the respondents. To obtain significant result of the questionnaire was forwarded to construction professionals from client, consultant and contractor companies working in RMP. Total 130 respondents were selected and feedback was received from 102 respondents.

In first stage the literature review conducted about MEP system in building projects and metro stations to identify the research gap. In second stage, implemented quantitative approach, a questionnaire design was developed to achieve the research objectives. In third stage, pilot study was carried out to check the feasibility and clarity of questionnaire by taking open suggestions from construction professionals prior to final field survey. In fourth stage, after pilot test final survey was conducted for data collection. Furthermore, in the fourth stage, rework causes during the installation of the MEP were categorised into three sub-groups according to project management triangle i.e., quality, cost and time and feedback was analysed in SPSS. In the fifth stage research results were revealed according to the objectives. Finally, in sixth stage conclusions were drawn and suggestions for MEP engineers and construction professionals were given to improve the performance of in upcoming projects.

3.1 Questionnaire Design

The questionnaire design composed of two main parts. The first part intended to collect general information about the respondent's qualification level, field of specialization, the nature of their company, project subsection, and work experience. The second part include three subsections about the causes of reworks during installation of MEP system in metro stations. The subsections identify the causes of rework and its impact on quality, cost and time based on a five-point Likert scale as shown in Table 3.1.

Table 3.1: Five Point Likert scale [38]

Numerical Value	Response Category (Scale)
1	Very Low Impact
2	Low Impact
3	Medium Impact
4	High Impact
5	Very High Impact

The reliability test was conducted on final questionnaires using Cronbach's alpha method [29]. Higher the alpha values are more desirable (range from 0 to 1) if the value reached greater than 0.70 considered as a reliable measure [43]. After conducting the reliability test for the questionnaire in SPSS the Cronbach's alpha (α) value evaluated α= 0.91, which was an excellent reliability scale. The reliability test result is shown in Table 3.2.

Table 3.2: Reliability Test of Questionnaire (SPSS- V26)

Cronbach's Alpha	No of Items
0.91	45

3.2 Population and sampling

Sampling is the process of choosing a sample from the defined population [48]. The sample size for this study was calculated 130 which was derived by using area population formula. The confidence level considered as 95% shown in below equation (Mc Naughton & Cowell, 2018):

$$S = X^2 NP(1-P) \div d^2 (N-1) + X^2 P(1-P)$$

Where:

S = sample size from the finite population (Method: probability random sample)

X = based on a confidence level of 1.96 for 95% confidence was used for this study

d = Precision desired, expressed as a decimal (i.e., 0.05 for 5% used for this study

P = Estimated variance in Population as a decimal (i.e., 0.5 for this study)

N= total number of populations (N= 195 for this study)

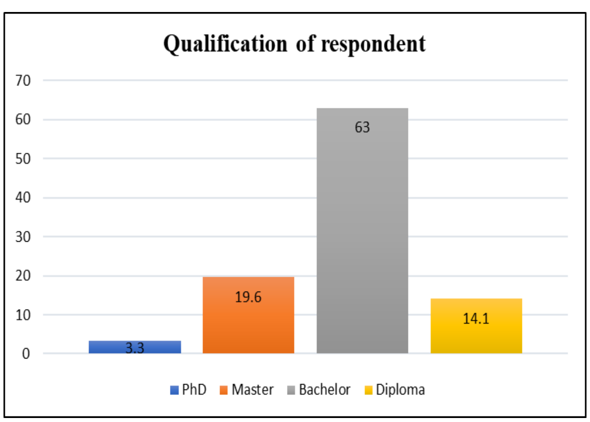
$$S = \frac{(1.96)^2 \times 195 \times 0.5\,(1-0.5)}{(0.05)^2 \times (195-1) + (1.96)^2 \times 0.5\,(1-0.5)} \approx \mathbf{130}$$

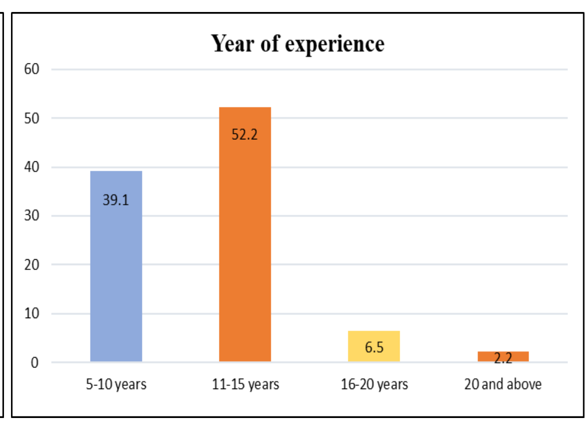
4. RESULTS & DISCUSSIONS

The research revealed the objectives by identifying the potential causes of reworks associated with MEP system installation and their impact on overall project performance.

4.1 Demographics of Respondent's

The demographics of the respondents is an important factor for the accuracy and acceptability of the research results. As per selected sample total 130 questionnaire survey forms were distributed to construction professionals working in three main stations of RMP and 102 feedback were received. The Figure 4.1 shows demographic information of respondents from clients, consultants, contractors and subcontractor companies employed in main stations of RMP.





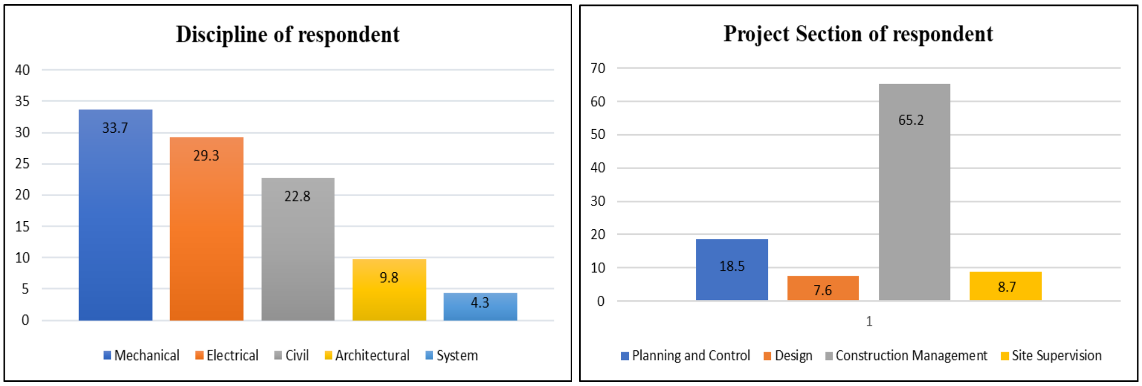


Figure 4.1: Demographic information of respondents

4.2 Rework impact on project during installation of MEP system

This section elucidates the result obtained after analysis of questionnaire in SPSS V26 as specified in the research methodology. The rework causes and impact on project performance during the installation of the MEP system in metro stations were further classified into quality, time (or schedule), and cost. Each group had a unique self-explanatory rework causes identified in installation of MEP system which influence and impact the project's overall performance.

4.2.1 Rework impact on quality

This section comprises of 15 rework causes observed during the installation of the MEP system in Riyadh Metro transfer stations; the results of rework impact on project quality is illustrated in Table 4.1

Table 4.1: Rework causes and impact on Project Quality

S/ No.	Cause of Rework	Mean	Std. Deviation	Impact Level
1.	Non-compliance with specifications and standards	4.10	0.76	High
2.	Poor coordination between the design and construction team	4.04	0.81	High
3.	Poor workmanship	4.02	0.59	High
4.	Lack of knowledge and experience of project staff	3.94	0.83	Medium
5.	Poor communication among different project stakeholders	3.91	0.86	Medium
6.	Shortage of skilled workers	3.79	0.65	Medium
7.	Work resume prior to the approved drawings	3.78	0.92	Medium
8.	Fast-tracking and crushing of activities due to limited time	3.71	0.61	Medium
9.	Negligence in taking clearance from Civil/ Arch before MEP	3.68	1.02	Medium

	installation			
10.	Lack of knowledge and experience of project staff	3.58	0.92	Medium
11.	Use of low-grade construction materials	3.51	0.95	Medium
12.	Lack of collaboration between Equipment manufacturer and design	3.48	0.85	Medium
13.	Over-designing results in quality issues	3.23	0.83	Medium
14.	Failure to protect the completed works	3.17	1.13	Medium
15.	Delays in submission of inspection requests for work approval	3.10	0.68	Medium

The results in Table 4.7 revealed that 3 causes of reworks, "Non-compliance with specifications and standards", "Poor coordination between the design and construction team" and "poor workmanship" were given high impact on project quality by the respondents with a mean value greater than 4. Moreover, remaining causes of rework had a medium impact on project quality with mean scale value greater than 3.

4.2.2 Rework impact on cost

This section is composed of 15 rework factors that influence cost performance during the installation of the MEP system in Riyadh Metro transfer stations; the results of rework impact on project cost are demonstrated in Table 4.2 below:

Table 4.2: Rework causes and impact on Project Cost

S/ No.	Cause of Rework	Mean	Std. Deviation	Impact Level
1.	Poor cost estimation for construction work package	4.09	.346	High
2.	Change in design on client request after work completion	4.03	1.03	High
3.	Incomplete design during installation works at the site	4.01	.744	High
4.	Change in design due to clashing with MEP services installation	3.80	.986	Medium
5.	Concrete demolishing and chipping due to equipment size issues	3.60	.610	Medium
6.	Conflict of interest between project stakeholders	3.52	.762	Medium
7.	Missing openings for piping and HVAC duct in floor/ walls	3.50	1.01	Medium

8.	Unfeasible site condition for installation of MEP system	3.46	1.02	Medium
9.	MEP material costs escalated in the market	3.45	.732	Medium
10.	Changes asked by the Engineer for quality control	3.43	.730	Medium
11.	Overdesign due to lack of construction experience	3.15	1.04	Medium
12.	Repair of damage caused by another subcontractor	3.11	.958	Medium
13.	Fast-tracking of activities for schedule compression	2.65	.965	Low
14.	Cost variation requested by the contractor due to Site limitation	2.57	1.00	Low
15.	Conflicts within the project team members	2.47	.777	Low

The respondents agreed on 2 causes of reworks "Poor cost estimation for construction work package", "Change in design on client request after work completion" and "Incomplete design during installation works at the site" has a high impact on project cost with mean scale greater than 4 and rest causes have medium and low impact.

4.2.3 Rework impact on time

According to the construction professionals employed in RMP, this group comprises 15 rework causes related to MEP installation in metro stations and its impact on project time. The results of rework impact on project schedule or time are demonstrated in Table 4.3 below:

Table 4.3: MEP system installation-related reworks impact on Time

S/ No.	Cause of Rework	Mean	Std. Deviation	Impact Level
1.	Payment issues or delays in monthly progress claims	4.08	.968	High
2.	Delay in submission of shop drawings for review/ approval	4.01	.977	High
3.	Delay in delivery of the materials by supplier	3.95	.572	Medium
4.	Poor coordination between design and construction	3.82	.585	Medium
5.	Inefficient selection of the subcontractor	3.78	.723	Medium
6.	Effect of uncontrolled causes such as pandemic conditions	3.77	.961	Medium
7.	Failure in project construction planning (construction stage)	3.64	.688	Medium
8.	Strikes by workers due to wages and payments	3.59	.914	Medium

9.	Shortage of skilled labor required to complete tasks	3.55	.731	Medium
10.	Logical dependencies in phase of MEP installations	3.44	.856	Medium
11.	Area not released by Civil/ Arch for MEP installation	3.39	1.27	Medium
12.	Prolong procedure for change requests and approvals	3.11	.887	Medium
13.	Lack of using advanced construction equipment	2.92	.683	Low
14.	Acts of God/Force major i.e., weather conditions, summer, rain and storm etc.	2.86	1.11	Low
15.	Poor site conditions, such as water, electricity and food	2.72	.927	Low

The respondents agreed on 2 causes of reworks "Payment issues or delays in monthly progress claims" (4.08) and "Delay in submission of shop drawings for review/ approval" (4.01) has a high impact on project time delay with mean scale greater than 4 and rest causes have medium and low impact.

4.2.4 Overall impact on project performance

The respondents agreed on the rework "impact on quality" during the installation of the MEP system in metro stations is extreme with a mean value of 3.45 and was ranked first. The "impact on time" with a mean of 3.37 was ranked as the second, "impact on cost" with mean 3.28 was ranked as third cause to impact overall project performance. The figure 4.2 represents the graphical version of reworks impact on project performance of project (quality, time cost and scope).

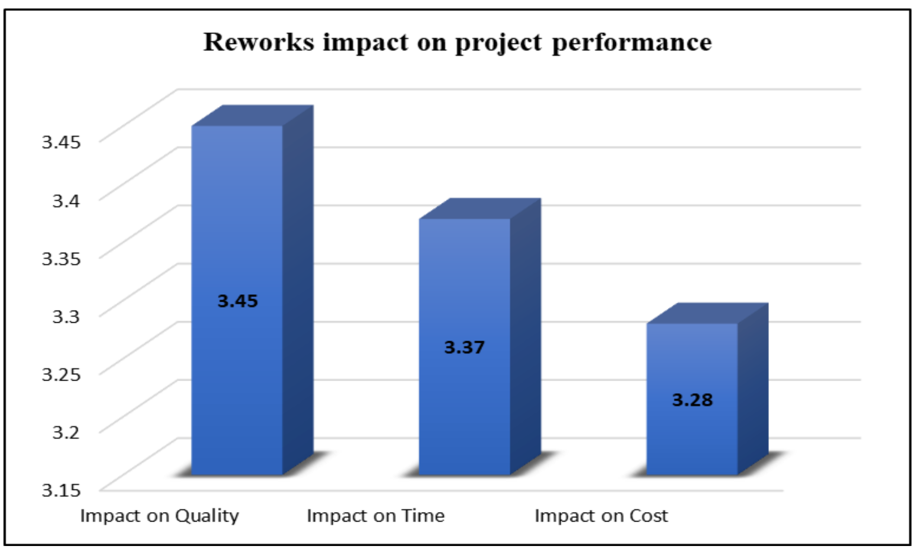


Figure 4.2: Reworks impact on project performance

The respondents agreed on the rework "impact on quality" during the installation of the MEP system in metro stations to be extreme as compared to its "impact on time" and "impact on cost". Therefore the reworks in overall affect the project performance.

5. CONCLUSION AND RECOMMENDATIONS

The endemic rework occurrences and it influence on performance and productivity should not be deemed as unresolvable. The research explored that undesired outcomes related to rework can be substantially improved in Saudi Arabia through developing of adequate awareness as well as organized strategies regarding rework management. This study has extended the knowledge and tried to fill the gap of construction management about MEP system installation related rework in construction of metro stations in Saudi Arabia. The duration required for MEP installation and testing activities in mega building projects exceeded that of civil and architectural works. Proactive measures, such as effective coordination, process improvement in construction management, and skill improvement are essential for ensuring successful project performance.

The first objective of this research was set as "to identify rework causes during installation of MEP system in metro stations" The rework causes were divided into four categories based on their degree of influence on project KPI's. Quality in construction projects specifies the need of client for which it was executed. Failure to meet project specifications leads client dissatisfaction and potentially cause reworks. Inadequate coordination, poor workmanship and lack of qualification and experience of project engineers were considered common causes that impact project quality. Impact of rework on cost occurred due to poor cost estimation for construction work package, change in design and use of not approved drawings in construction. Significant portion of rework in metro stations resulted from contractors undertaking MEP system installation work without obtaining design approval.

The second objective of this research was "to evaluate the impact of rework on project overall performance in metro stations". In RMP Saudi Arabia impact of rework during MEP system installation found highest on quality than impact on time and cost. The noncompliance with specifications and applicable standards, poor workmanship was considered as high-potential rework causes that impact quality measure of the project. Reworks impact major key performance indicators of construction project, but the influence on quality might stand out more prominently because it directly relates to the final performance. The reliability and client satisfaction, payment issues or delays in monthly progress claims are some common root causes that have high impact on cost. Rework often involves additional resources i.e., labor, materials and equipment which can escalate costs. Significantly, poor cost estimation for the construction work package, changes in design on client request after work completion and incomplete design during installation works at the site has direct impact on project overall performance.

Based on the findings of the study, the authors recommend the following measures to reduce the effects of rework and to improve projects performance in Saudi Arabia:

i. Improve the coordination among construction and smooth communication between design and construction to avoid reworks. Relevant technical coordinator shall be assigned to resolve conflict in the project.

ii. Conduct coordination meetings to identify construction sequence and to avoid clashes between MEP and civil architecture works

iii. Not approved design during execution always lead reworks, MEP contractors are advised to provide updated and approved drawings to site installation teams.

iv. MEP services demand technical skill; hence, the contractors and consultants are advised to hire experienced workmanship and qualified engineers respectively.

v. Project specifications and standards should follow to reduce rework in MEP system installation. The site engineers shall direct by immediate managers to follow the project specifications and related codes.

vi. As per research in mega projects MEP system cost reached up to 30-40 % of project total cost and 40-50 % of project overall duration. Therefore, the client, consultant and contractor companies are advised to organize MEP discipline lead by MEP manager to improve project performance.

vii. Involve manufacturer representative during installation of MEP equipment such as chiller, pump, panels etc. and expedite inspection request earlier to avoid any additional rectification.

viii. The research focuses only on the construction of metro stations in future studies may target different construction projects to identify rework impact on project performance.

Rework has been established as a major factor for construction project quality, cost and time overruns. Therefore, project participants should be alert and kept good foresight in identifying rework triggers and mitigate them before impact on-site to avoid rework emergence in forthcoming building projects.

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