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Triggers of schedule overrun in construction of railway projects; A quantitative analysis of rail transportation networks in Saudi Arabia

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Abstract: The Kingdom of Saudi Arabia (KSA), a nation of vast scale and economic influence, ranks among the world's top 25 economies and leads the Arab world. However, it faces significant disparities in its transportation infrastructure. The importance of railway projects in KSA cannot be overstated, as modern electric railway networks including long-distance rails and metro systems within cities—serve as foundational pillars for economic growth and social development. These projects are critical for reducing reliance on fossil fuels, lowering carbon emissions, and fostering cleaner air and a more sustainable environment. With the global emphasis on fast, secure, and convenient transportation networks, extensive research has explored schedule overruns in railway construction projects. Recognizing the need for seamless and timely delivery in upcoming transportation projects, it is crucial to analyze and address the triggers of schedule overruns faced by professionals during the construction of transportation networks in KSA. This study adopts a quantitative analysis approach, involving a brief review of schedule overrun triggers highlighted in the literature and evaluated by construction professionals based on their field experience during the execution of railway (metro and train) projects in Saudi Arabia. Out of a sample size of 291, a total of 230 responses were found to be accurate. The data was then quantitatively evaluated using statistical tools. The study reveals that the primary schedule overrun triggers in railway construction projects, with higher Frequency Impact Index (FII) related to construction parties, include: "changes initiated after completion of work," "inefficient selection of contractors," "lack of coordination," "delays in approval of documents," "non-compliance with specifications," and "material delays by suppliers." These triggers were ranked by professionals based on their experience. The findings of this study provide crucial insights for the Saudi Arabian railway construction industry, offering a refined approach to optimize future projects. Specifically, it aims to contribute to the industry's growth by identifying and mitigating key trigger factors that may cause schedule overruns in railway developments.

Keywords: Railway, Metro network, Construction projects, Schedule overrun, Saudi Arabia.

1. Background

As a foundational pillar of economic growth and societal development the construction projects significance cannot be overstated. Mega infrastructure projects such as long distance rail and inside city metro networks provides necessary support and facilities that allow a country, city, or area to function and its economy to thrive [1]. Considering the importance of rail transportation network in countries any delays in the construction of railway projects can create significant losses [2]. For decades, the construction sector has demonstrably underperformed compared to other major industries

in terms of productivity. Project schedule overruns are a clear indicator of this but the underlying causes are complex and interwoven a deeper analysis of the interconnected causes is crucial [3]. The construction sector's inherent dynamism, influenced by both internal and external forces creates significant challenges for performance management. This coupled with the unique nature of its projects and unpredictable circumstances often leads to deviations from projects planned outcomes. Schedule is increasingly recognized as primary indicators of project success. Consequently, delays are frequent and severely damage project reputation [4]. Project completion without schedule overruns is a hallmark of efficiency and success in construction industry and the rankings of project are heavily influenced by completion speed, cost-effectiveness, quality, and adherence to specifications [5].

The rapid expansion of economic development worldwide has also fostered an environment aspects that strongly encourages public transport networks globally for achieving sustainable goals [6]. Across the globe, construction projects consistently struggle to meet their deadlines, and even large-scale infrastructure projects like metro and railway networks, despite employing advanced project management tools and resources [7]. The widely accepted definition of a successful construction project includes completion within the agreed schedule and budget adherence to project specifications, and ensuring the sponsors satisfaction with the outcome [8]. Subsequently, completing projects on time is a key indicator of efficiency and schedule is one of the key metrics for determining project performance and success [9].

Construction industry is under considerable scrutiny due to persistent issues with project delivery, financial performance, and a lack of timely value creation, leading to widespread criticism for delays and poor overall accomplishment [10]. Research published by the World Bank in 2014 projected that the potential economic benefits of timely infrastructure projects such as railways could be substantial potentially contributing approximately 1% of a nation's GDP annually [1].

The Saudi Arabian construction sector is witnessing accelerated growth in all infrastructure domains, from urban to rural transportation. The government’s strategic allocation of substantial resources towards advanced infrastructure especially in public transportation within metropolitan cities [3]. 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 end of 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 [11]. Therefore, adhering to construction project deadlines is crucial for realizing the Kingdom's vision and fostering sustainable development.

2. Literature Review

When the stipulated completion time is pushed forward, the project is said to have experienced schedule overrun [12]. Schedule overrun refers to the late completion or late delivery, from the time specified or agreed by all parties of the construction project. The main causes for the schedule overrun are financial problems, late payments for the completed work and on-going work, change orders, organizational changes etc. [8].

A global epidemic of construction delays continues to hinder the industry. The lack of information on their occurrence prevents effective countermeasures. However, trigger of issues and implementing strategies to reduce delays would yield considerable sustainable benefits for the construction sector

[13]. Despite its crucial role, the construction industry struggles with significant challenges, including poor financial performance, inflated project delivery costs, substandard quality, material waste, and project failures [14]. Globally, the construction industry is consistently observed to struggle with implementing strategies to ensure on time delivery throughout both the design and execution phases of infrastructure projects [15].

2.1 Railway networks in Saudi Arabia (existing and planned)

The expansion projects Railway networks as is known all over the world are effective in moving large volumes of bulk commodities over long distances and according to regular schedules and when compared to other means of transport can often be cheaper [16]. Kingdom of Saudi Arabia wants to complete the national plan of constructing 9,900 km of railways by 2040, which also including the 2,750km North-South Railway from the north to Riyadh and the 950km Landbridge from Riyadh to Jeddah [16]. In addition, the government is ambition to expand its rather modest railway, which currently links Riyadh via two railway lines to the port of Dammam. There are four big projects planned by which the dream finally looks set to become a reality as listed below [17].

i. The Saudi Landbridge: this will involve building a new 950 kilometres line from the capital, Riyadh, west to the Red Sea port of Jeddah, and a 115-kilometre line from Dammam north along the Gulf coast to Jubail; the existing Riyadh-Dammam railway will also be upgraded.

ii. The Western Railway: 750 kilometres of new lines from Jeddah southeast to Makkah, and northeast to Madinah and Yanbu. The 444 km Haramain High Speed Rail linking Makkah, Jeddah and Madinah are the part from this line [18].

iii. The North-South Railway: a 1400-kilometre mineral railway running between mines at Al Jalamid and the port of Ras Az Zawr was completed in mid-2013.

iv. GCC railway: A 1940 km international railway network is proposed to link all the Gulf Co-Operation Council member states. This would connect Saudi Arabia to the Etihad Rail network which is under construction in the UAE. The five railway projects are shown in Figure 1.

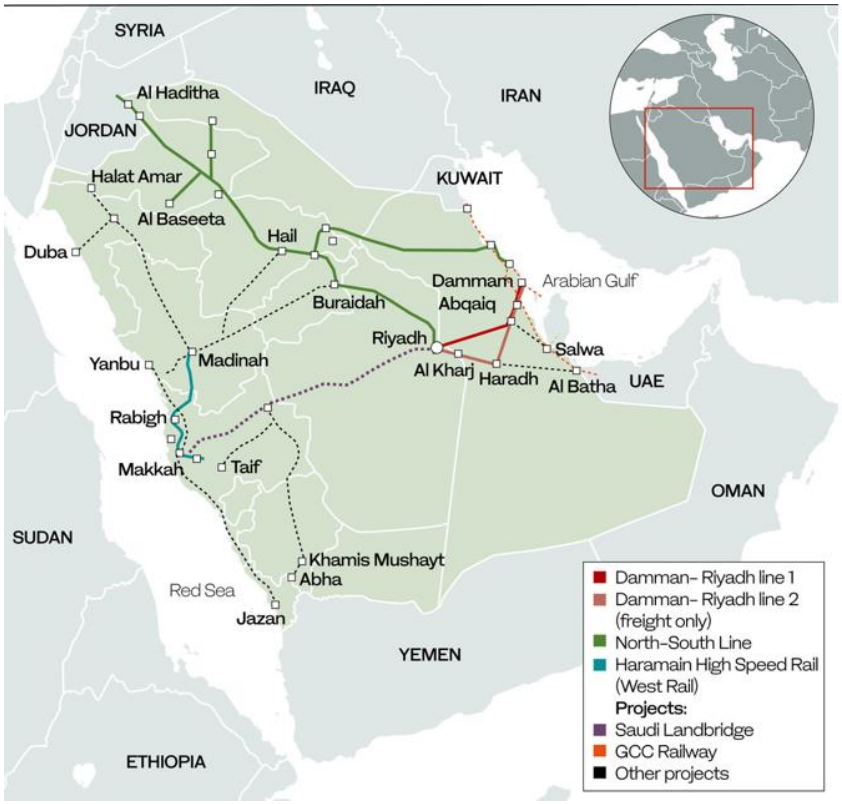

Figure 1: Saudi Arabia Railway networks

2.2 High Speed Rail in Saudi Arabia

High Speed Rail (HSR) is new rail technology developed in 20th century, which consists of a special infrastructure that allows trains running at a speed over 250 km per hour. There is no standard definition of what constitutes HSR. In all cases, high speed is a combination of all the elements that constitute the established system infrastructure. One of the HSR definitions depends on infrastructure comprises with three different types of lines [1].

The Haramain High Speed Rail (HHSR) Project is the first high speed rail project built in the Middle East. It provides the fastest and the safest mode of conveyance for the pilgrims, Umra performers, and other passengers. The project provided a new electrified passenger railway line, between Makkah, Jeddah and Madinah approximately 450 km in length with a commercial operating speed of 320km/h. This network is providing a fast, comfortable, reliable and safe mode of transport between the Holy cities utilizing state of the art proven technology [18]. With a peak-time capacity exceeding 8,000 passengers per hour during pilgrimages, this high-density line relies on 35 trains, each accommodating over 500 passengers. The system integrates cutting-edge technology and prioritizes sustainability to minimize its environmental footprint [19]. Moreover, there are multiple objectives of HHSR such as speed, capacity, reliability, prestige, economic development and environmental sustainability etc. [16]. The Haramain High Speed Rail project map shown in Figure 2.

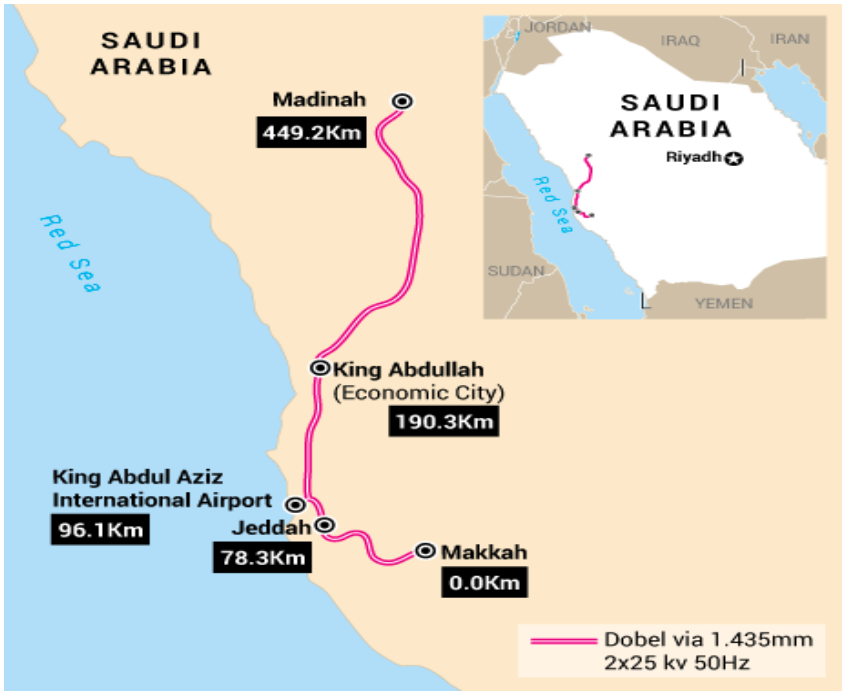

Figure 2: The Haramain High Speed Rail map

2.3 Metro networks in Saudi Arabia

Congestion at various traffic junctions and squares in Jeddah has increased tremendously, even after spending millions of riyals on new underpasses and overpasses. The municipality, however, has promised that the problem of congestion will end by 2030 with the completion of new infrastructural projects such and Riyadh metro project and Al Mashaaer Metro [19].

Riyadh metro network

Riyadh Metro (Arabic: قطار الرياض) is a rapid transit system serving Riyadh, the capital of Saudi Arabia. Part of the King Abdulaziz Project for Riyadh Public Transport. The network consists of six lines connecting 85 stations spanning a combined length of 176 kilometres it is the longest driverless metro in the world. The Metro Project is the backbone of the public transport network in Riyadh, capable of transporting 3.6 million passengers per day in initial phase the project is open for public partially. With six lines cover most of the densely populated areas, public facilities, and the educational, commercial, and medical institutions [20]. The experts in public transportation around the world are interested to improve the service quality of transportation in contrast to conventional building projects, the design life of Riyadh metro assumed as 100 years and accordingly, the metro stations are fully furnished with modern systems to accommodate the future population [11]. This mega project was initiated in March 2014 and currently near to completion, according to The Royal Commission for Riyadh City (Arabic: الهيئة الملكية لمدينة الرياض) Riyadh metro will be operational for public in December 2024 [9]. The Riyadh Metro project map shown in Figure 3.

Figure 3: Riyadh metro transportation network plan

Makkah Al Mashaaer Al Mugaddassah Metro

The Al Mashaaer metro system build in Makkah is a special metro line dedicated to support pilgrim service. With a gross length of 18 km Al Mashaaer metro built to carry pilgrims during the annual Hajj period opened in November 2010 in the city of Makkah, Saudi Arabia [21]. Claimed to have the highest capacity of any metro in the world, it operates for seven days a year, and is used exclusively as a shuttle train for pilgrims between holy sites in Makkah, Mount Arafat, Muzdalifah and Mina to reduce congestion caused by thousands of buses and cars during the Hajj. It is the second metro system on the Arabian Peninsula, after the Dubai Metro [22]. The Al Mashaaer metro map shown in Figure 4.

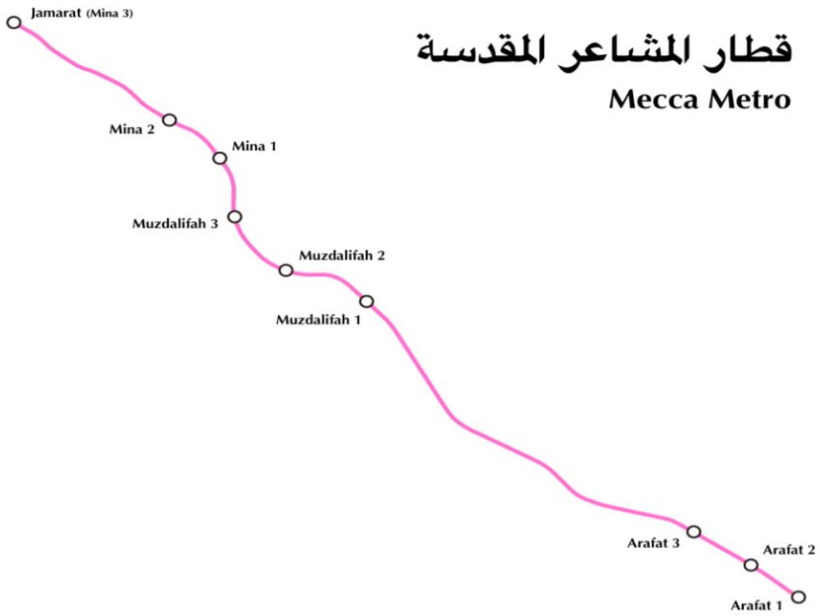

Figure 4: Al Mashaaer metro network in Makkah

2.4 Future metro networks in Saudi Arabia

The city of Makkah, home to 2.386 million people as of 2022 and the third most populous in Saudi Arabia, is grappling with unchecked urban sprawl. This haphazard growth, characterized by expansion into previously undeveloped areas and the levelling of historic mountains near Al-Masjid Al-Haram, is leading to environmental degradation and aesthetic decline as the city seeks to expand its urban capacity [23]. Saudi Arabia has restarted the feasibility study for the Mecca Metro which will reached to 188km in gross length along with existing 18km operational network [16]. The future plans for Mallah metro is shown in Figure 5.

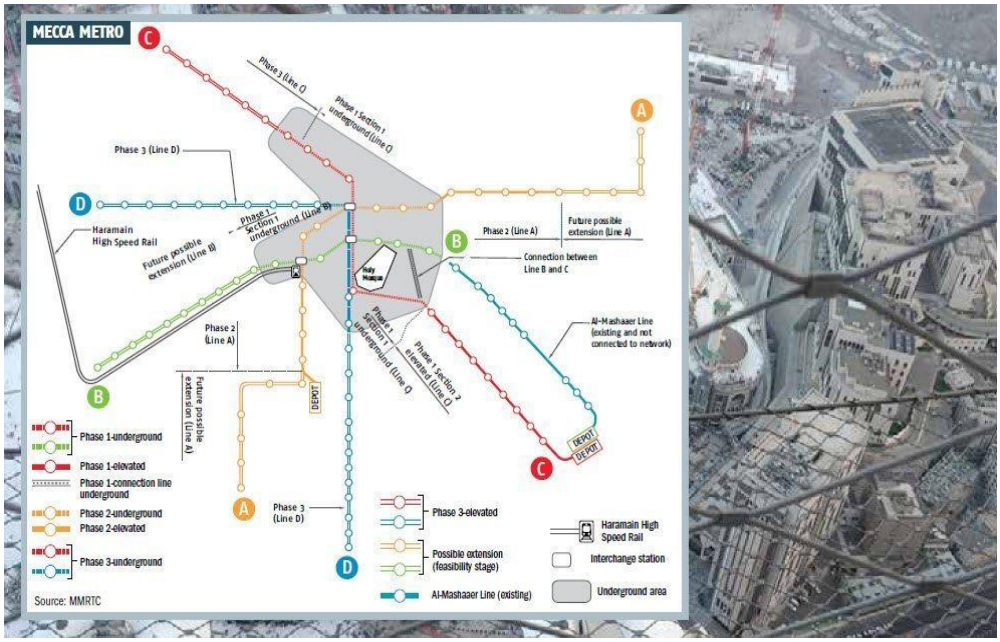

Figure 5: Makkah metro networks plan

The Jeddah Metro is planned to have three major lines Orange, Blue, and Green. The total length of the network is planned to be 152 kilometres with 92 stations. The Orange Line will be 84km and is split into two parts, the Blue Line 36km and the Green Line 32km. Three metro lines are planned to open soon as part of the urban transport development strategy [24]. When discussing metro networks in Saudi Arabia, it's important to distinguish between different cities. Al-Madinah Al-Munawwarah, the second holiest site spans an area of 490 square kilometres. In March 2024 the Madinah Metro Development Authority (MMDA) awarded 12-month contract to carry out feasibility studies and produce preliminary design for the metro [22].

2.5 Triggers of schedule overrun in construction projects

Practitioners and scholars express concern about construction projects that are unable to achieve the specified goals or objectives[25]. In mega projects like railway and metro networks the construction schedule overruns is the time beyond the contractual completion date agreed upon by all parties in beginning of contract [12]. A construction schedule overrun occurs when project takes longer time than originally planned or experiences unforeseen setbacks [26]. The railway and metro projects are dynamic in nature with transformation of advance and modern technology ultimately increases project complexity, leading to an increase in the number of challenges for stakeholders during design, construction and final completion stage [27].

Effective project management is essential for ensuring success and preventing schedule overruns [28]. The schedule overruns are common in construction projects and can be triggered by multiple factors [29]. One major cause is procurement delays, particularly for critical systems such as MEP, rolling stock, and workshop equipment, which are often affected by supply chain disruptions and long lead times, ultimately impacting the overall project timeline. Additionally, unforeseen site conditions such as modifications, reworks, demolishing, design revisions, and a shortage of skilled workers can lead to increased time and costs overruns in construction [30].

In railway projects, schedule delays frequently result from design modifications after construction has begun, requiring redesign, change orders from contractors, material shortages, inadequate planning, and the rescheduling of work packages. Furthermore, previous research identified additional factors contributing to schedule overruns during project delivery and implementation, including lack of construction machinery on-site, adverse weather conditions, contractor financial instability, delays in subcontractor payments, and unapproved design implementations at the project site [31].

2.6 Triggers of schedule overrun in railway projects of Saudi Arabia

The construction industry in Saudi Arabia is undergoing rapid expansion, ranking as the second-largest sector in the national economy [32]. Contributing approximately 30% to 40% of the country's GDP [3], it holds the title of the largest construction industry in the Middle East, with annual expenditures exceeding USD 120 billion and employing over 15% of the national workforce [25]. However, despite its economic significance, the industry continues to struggle with persistent schedule overruns, particularly in large-scale railway and metro projects [9]. These schedule overruns not only tarnish the sector’s reputation but also result in substantial cost escalations. Given the growing complexity of construction projects, proactive identification and management of triggers related to schedule delays are essential for effective project control [3].

Saudi Arabia's Vision 2030 emphasizes timely project execution as a cornerstone for national progress and development. Successful project delivery is often evaluated based on the "iron triangle" ensuring projects are completed on schedule, within budget, and meeting the required quality standards [26]. However, in an increasingly competitive and globalized market, achieving these objectives has become more challenging. A critical review of the literature on schedule overruns reveals that these delays are a globally recognized issue in construction projects. Key factors frequently cited by researchers include inexperienced design teams, inefficient decision-making and change control procedures, low labor productivity, inadequate site management, rework due to errors, non-compliance with specifications, coordination and communication breakdowns, delays in approval processes, a shortage of skilled professionals, and ineffective project planning and scheduling. These factors are particularly prevalent in Saudi Arabia's railway and metro construction sector [11].

Project performance is inversely correlated with schedule overruns, impacting key parameters such as time, cost, and quality. Despite advancements in technology and its integration into project management, schedule overruns remain a critical concern specially in mega projects of railways. It is imperative for project clients, consultants, and contractors to develop a deeper understanding of the primary triggers affecting construction timelines [17]. Addressing these issues effectively requires a data-driven approach to identify and mitigate risks at an early stage.

A survey conducted on railway construction projects in Saudi Arabia revealed that the most significant causes of schedule delays include contractors' financial difficulties, delays in owner payments, contracts awarded to the lowest bidder, frequent change orders during construction, ineffective project scheduling, a shortage of skilled manpower, and poor site management by contractors [31]. Additionally, external factors such as adverse weather conditions, legal and regulatory challenges, and overall economic instability exacerbate project delays. Prolonged periods of bad weather, for instance, can force construction activities to pause, leading to extended timelines and cost overruns [20]. This study aims to provide a comprehensive assessment of the key triggers responsible for schedule overruns in Saudi Arabia's railway construction projects. By analyzing their impact and interdependencies, the research seeks to facilitate early intervention, ensuring the timely and cost-effective completion of future railway and metro networks in KSA.

3. Methodology

This study utilized both primary and secondary data sources. Primary data was collected through a structured questionnaire survey, while secondary data was gathered from literature reviews and experiential records. A quantitative research approach was adopted, with the survey designed to identify key triggers of schedule overruns, wherein data is gathered through the distribution of questionnaires among employees with prior experience in railway construction. The target population consists of 291 respondents from Morgan's identification as highlighted in Table 1. In return total 230 responses were found accurate for further analysis. Respondents include from clients, consultants, contractors and subcontractors. The questionnaire survey was crafted using the triggers of schedule overrun aligning with the study's objectives. A total of 30 identified factors that trigger schedule delays in railway construction projects that are categorized into the subgroups include owner-related, contractor related, consultant related.

Table 1: Morgan table for sample size

N	S	N	S	N	S
130	97	300	169	800	260
150	108	400	196	900	269
170	118	500	217	1000	278
190	123	600	234	1100	285
200	132	700	248	1200	291

N is population size and **S** is sample size according to Morgan [33].

The 5 points Likert scale to capture the level of importance and its frequency of occurrence and for the level of importance, Likert scale used for each variable by the respondents is shown in Table 2.

Table 2: Likert Scale for Weighting Responses

Weightage of Trigger	Likert scale
Strongly disagree	1
Disagree	2
Slightly Agree	3
Agree	4
Strongly Agree	5

Finally the data was evaluated through statistical methods in SPSS (Statistical Package of Social Sciences) software by computing the variables. The Frequency Adjusted Importance Index (FAII) was calculated from below equation_1. The FAII value is the multiplication of Relative Importance Index (RII) and Frequency Index (FI) values, calculated through equations 2 and 3.

FAII = (RII×FI)/ 100 Equation----------1

Where:

RII = Relative Importance Index (measuring significance of the delay factor)

FI = Frequency Index (measuring how often the delay factor occurs)

RII = ∑W/ (A×N) Equation----------2

Where:

W = Weight assigned to each factor by respondents (based on Likert scale responses, e.g., 1 to 5)

A = Highest possible weight (e.g., 5 for a 5-point Likert scale)

N = Total number of respondents

FI = (N/n) ×100 Equation----------3

Where:

n = Number of respondents who identified the factor as a cause of delay

N = Total number of respondents

4. Quantitative Analysis and Results

The data collected from construction professionals, including clients, contractors, consultants, and subcontractors involved in railway and metro projects in Saudi Arabia, was analyzed using SPSS. Table 3 presents the top ten Owner-related triggers contributed in schedule overruns in railway projects of KSA.

Table 3: Triggers of schedule overruns in railway construction (Owner related)

Sr. No	Triggers of schedule overruns in Railway project in KSA	RII (%)	FI (%)	FAII (%)
1	Delays in monthly claims submitted by contractor	76.78	73.05	68.02
2	Change initiated after work completion	75.65	72.57	67.01
3	Prolong procedure for change requests and approvals	74.24	72.38	59.76
4	Lengthy regulatory policies	79.34	64.74	58.15
5	Inefficient selection of contractor and subcontractors	71.43	72.38	58.70
6	Inappropriate type of contract used	74.48	65.71	56.94
7	Lack of coordination with consultant and contractor	74.38	64.95	54.22
8	Selection of unrealistic contract	71.43	64.76	53.39
9	Contract awarded to the lowest bidder	70.48	57.52	52.66
10	Changes in government regulations and laws	75.05	56.52	48.17

The resulting averages were ranked in descending order according to the highest average of FAII in terms of percentage. In Table 3 the top ten Consultant related triggers contributed to schedule overruns.

Table 4: Triggers of schedule overruns in railway construction (Consultant related)

Sr. No	Triggers of schedule overruns in Railway project in KSA	RII (%)	FI (%)	FAII (%)
1	Poor coordination between design and construction	75.88	73.36	67.22
2	Delay in approval of drawings and technical documents	74.65	72.67	64.11
3	Insufficient details in contract documents	73.24	71.36	64.86
4	Unproductive project planning and scheduling	79.32	70.74	63.15
5	Delays in inspection requests for work approval	70.45	70.37	59.71
6	Lack of experience of the construction management staff	74.47	64.71	59.14
7	Improper installation and test method	73.32	63.91	56.24
8	Mistakes and discrepancies in design	71.42	63.74	52.32
9	Not monitoring regular risks and occurrence of accidents	70.41	55.52	50.64
10	Improper project feasibility study	74.22	54.57	49.18

The resulting averages were ranked in descending order according to the highest average of FAII in terms of percentage. In Table 3 the top ten Contractors related triggers contributed in schedule overruns.

Table 5: Triggers of schedule overruns in railway construction (Contractors related)

Sr. No	Triggers of schedule overruns in Railway project in KSA	RII (%)	FI (%)	FAII (%)
1	Non-compliance with specifications and standards	75.76	73.12	76.02
2	Lack of collaboration between manufacturer and design	75.63	75.56	75.01
3	Materials delivery delays by supplier	73.25	70.38	73.76
4	Skilled labor shortage to complete tasks	78.38	63.74	72.15
5	Incomplete design during works execution at site	70.46	71.38	68.70

6	Lack of using modern applications (BIM, Revit etc)	76.44	64.72	67.94
7	Unfavourable site condition	74.33	64.90	67.22
8	Integration of subcontractors	70.42	64.74	65.39
9	Labor productivity	71.47	60.53	60.66
10	Changes in materials during construction	74.35	57.51	59.17

The triggers were ranked based on the Frequency Impact Index (FII) and Frequency Adjusted Impact Index (FAII) percentages, providing a comprehensive understanding of the triggers contributing to delays in railway network projects in KSA. Table 3 elaborate top owner-related triggers of schedule overruns, ranked by FAII, highlight critical issues stemming from the client or owner's side. The most significant trigger is "Delays in monthly claims submitted by contractor" (FAII = 68.02%), indicating inefficiencies in the payment process, which can disrupt project timelines. Other notable triggers include "Change initiated after work completion" (FAII = 67.01%) and "Prolonged procedures for change requests and approvals" (FAII = 59.76%), reflecting challenges in decision-making and bureaucratic delays. These findings suggest that owners need to streamline approval processes, improve contractor selection mechanisms, and adopt more flexible regulatory frameworks to mitigate schedule overruns.

Table 4 elaborate top Consultant-related triggers primarily revolve around coordination, design, and planning inefficiencies. The top trigger, "Poor coordination between design and construction" (FAII = 67.22%), emphasizes the need for better integration between design and construction teams. "Delay in approval of drawings and technical documents" (FAII = 64.11%) and "Insufficient details in contract documents" (FAII = 64.86%) further highlight the critical role of timely and accurate documentation in preventing delays. These results indicate that consultants must enhance their coordination efforts, improve the quality of contract documents, and adopt more efficient planning and scheduling techniques to minimize delays.

Table 5 elaborate top Contractor-related triggers are dominated by issues related to compliance, collaboration, and resource management. The most significant trigger, "Non-compliance with specifications and standards" (FAII = 76.02%), highlights the importance of adhering to project requirements to avoid rework and delays. "Lack of collaboration between manufacturer and design" (FAII = 75.01%) and "Materials delivery delays by supplier" (FAII = 73.76%) underscore the critical role of supply chain management and stakeholder coordination. "Skilled labor shortage to complete tasks" (FAII = 72.15%). Contractors must focus on improving compliance, fostering collaboration, and addressing resource shortages to mitigate schedule overruns.

5. Conclusion

The study provides a comprehensive analysis of the triggers contributing to schedule overruns in railway network construction projects in the Kingdom of Saudi Arabia (KSA). By examining owner-related, consultant-related, and contractor-related factors, the research highlights the multifaceted nature of delays in large-scale infrastructure projects. The findings underscore the critical role of efficient project management, stakeholder coordination, and adherence to specifications in ensuring timely project delivery. The top owner-related triggers, such as delays in monthly claims, changes initiated after work completion, and lengthy regulatory policies, emphasize the need for streamlined administrative processes and flexible governance frameworks. Consultant-related triggers, including

poor coordination between design and construction, delays in document approvals, and insufficient contract details, point to the importance of effective communication, accurate documentation, and robust planning. Contractor-related triggers, such as non-compliance with specifications, material delivery delays, and skilled labor shortages, highlight the necessity of strict adherence to standards, efficient supply chain management, and adequate resource allocation.

The research findings offer actionable insights for stakeholders in the Saudi Arabian railway construction industry. By addressing these triggers through improved processes, enhanced collaboration, and the adoption of modern technologies, the industry can mitigate schedule overruns and optimize project outcomes. This, in turn, will support the nation's vision for economic growth, social development, and environmental sustainability. In conclusion, this research contributes to the body of knowledge on schedule overruns in infrastructure projects and provides a foundation for future studies aimed at further refining project management practices in the railway construction sector. By implementing the recommendations outlined in this study, stakeholders can enhance the efficiency and effectiveness of railway projects in KSA, paving the way for a more connected and sustainable future.

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