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Management of Complex Combination of Construction Interface among National & International Stakeholders on a Light Rapid Transit System Project in a Developing Country

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Abstract - *Light Rapid Transit System Projects (LRTS) are complex projects and thus require extensive planning and execution of multi-disciplinary interfaces throughout the project lifecycle. Developing countries are technically and financially constrained towards the execution of such projects leaving LRTS projects subject to fragmentation and contract work-splitting thus forming complex construction interfaces. The elaborate regime of dealing with construction interfaces from the perspective of contract work-splitting on LRTS projects is yet to be studied. This paper presents a case study of an LRTS project in a developing country involving an international contractor and focuses on the formation and implementation regime of complex interfaces formed as a result of contract work-splitting. The study applies a single case study-based approach and analyzes the empirical data using cause and effect analysis on the interface points (IP) to identify the key Interface Management (IM) issues at LRTS project. The IM issues are critically analyzed to outline unique issues in a developing country. Issues like the impact of international procurement on Interface Point (IP) inside an LRTS elevated station etc. are unique due to the background factors like the involvement of international multi-disciplinary contractors and the splitting of design among national and international parties. Findings will contribute towards devising appropriate contract work-split-based preventive construction interface methodologies along with Project Delivery System (PDS) for local and international contractors on LRTS projects.*

Key Words: **Light Rapid Transit System, Urban Rail Transit, Transportation Engineering & Planning, Engineering Management, Construction Interface, Interface Management, Contract Work-split**

1. INTRODUCTION

Light Rapid Transit System (LRTS) (e.g. Metro Train Projects), Mass Rapid Transit Systems (MRTS), or subway projects are the most advanced form of urban transport and infrastructure projects [1, 2]. These projects play an important role in transit-oriented development and promote sustainability and healthy communities [3]. These complex projects require multi-disciplinary inputs throughout the project lifecycle [4-6]. The prime focus of learned professionals, while planning an LRTS project, is always towards the design and implementation of interface plans in accordance with the business environment and stakeholder's requirements [7-9]. When these interfaces are not revealed and planned clearly, they generate countless disputes and progress delays [10]. The common interfaces are majorly planned between civil, electrical, and mechanical works or otherwise multiple contractors among whom the project is divided into packages [8]. The term interface carries multiple meanings [11]. An interface may be defined as a surface or shared domain, common boundary, or a connection point between two or more interdependent interface stakeholders or multiple entities working on a common project [12-14]. Besides the organizational interface, the construction interface may generally be subdivided into two major types i.e. physical & contractual excluding the identical ones [11, 15, 16]. Moreover, regardless of the type and complexity, Interface Management (IM) encompasses the management of communications, relationships, and deliverables among two or more interface stakeholders [7, 12].

Most of the studies related to IM implementation of LRTS projects or other mega-projects have been reported from developed countries like the United States of America [7, 17, 18], United Kingdom [19], China [12], Canada [13], Europe [20] Taiwan [10, 21], UAE [22]. These countries are financially sound and technically equipped with modern technologies like Building Information Modeling (BIM) [23] owing to excessive research and development (R&D) on automation and robotics technology in the construction industry [24]. Ahn, et al. [9] carried out studies on 45 large-scale engineering and construction projects and found out that the current IM practices are inefficient in mitigating the

issues in scope among stakeholders. In addition to the traditional method of managing interfaces which is contract defining responsibilities [9, 25], planning tools such as Railway Information Modeling (RIM) [26], (BIM) [27, 28], and techniques such as CladdISS [19], the interface object model [11], design structure matrix (DSM) [29] and interface scope allocation matrix [10] have been proposed. Shokri, et al. [30] and Shokri, et al. [31] introduced a five-step workflow-based process for IM starting from the identification of interface issues to their closing. A hierarchy of Interface Points (IP) to identify the interfacing activities, starting from the identification of IP between contract packages to interface closing, has been explored for interface planning and scheduling [31]. A comprehensive preventive interface design criteria approach considering the Design-Build (DB) type of contracts has also been recommended by researchers to avoid the interface complexities within a single contract [8]. The latest research has even moved from trying out IM practices, such as developing IM procedures and information systems, to improve interface norms, behaviors [32] and post-implementation performance and effects of IM practices on projects [33]. These studies have laid benchmark for construction industries all-over the world.

However, the studies carried out by researchers in developing countries like Indonesia [16], India [34], Egypt [4, 35], Iran [36], and some African countries Bensalah, et al. [26] have told a different story. [37] Found out that finance-related problems like loan issues are one of the major background constraints in the construction industry in developing countries. Diversified studies have further shown that the formation of contract (bidding and contracting factor) [38] i.e. complex work packaging forming a large number of external interfaces [22, 39], technical experience (technical engineering and site issue factor) management, coordination, multi-disciplinary teams were the potential sources of interface problems in such countries [16, 34, 40]. A qualitative study on 4 mega-projects in Iranian Infrastructure projects revealed that employer interference, poor decision making, and poor planning and scheduling are also some of the major causes of interface problems [36]. Studies have revealed that the financial and technical constraint is an alarming situation as the developing countries have to seek out international stakeholders to fulfill the gap [41], regarding the requisite technical as well as financial inputs [42]. This causes complex fragmentation of the projects and further increases the complexity of the project [43]. Nawi, et al. [44] defined fragmentation as the number of diversified organizations involved in a project. Another similar term is contract splitting which involves the bifurcation of a single purchase into two or more purchases like work-packaging [45]. The fragmentation in construction projects, leading to complex interfaces, in developing countries is also due to aspects including politics, bureaucracy, ambiguity and multiculturalism due to involvement of international stakeholders [9, 16, 41, 46]. Moreover, in comparison to the preferred type of contracts, for such complex projects, which is Engineering Procurement and Construction (EPC) single entity [32, 47] or other DB approaches [8], these projects are inevitably more fragmented [16] in developing countries due to lack of specialized contractors. Another innovation which is becoming common in Asia involves the splitting of single EPC contract into two or separate contracts to reduce taxation on offshore purchasing of materials [48]. Subsequently, the simultaneous execution of different contracts e.g. EPC with some other DB and Design Bid Build (DBB) types, incoherent at times, by different contractual-physical interfacing contractors results in the formation of enormous amount of complex interfaces leading to huge delays and iteration of re-works [10]. The work-splitting under an EPC contract usually causes specification issues, time and performance and coordination issues [48] eventually leading to failure of interface plan and delay of the project. A recent study conducted in Taiwan on interface in Urban MRTS projects collected and summarized the time extension data and revealed that more than 54% of extensions of time in contract durations were due to engineering interface issues [10]. Whereas, the studies in both developed and developing countries have identified the IM issues and have devised numerous mitigation strategies, the elaborate regime to deal design and construction interface in construction under the challenges and constraints in developing countries is yet to be studied. The impact of particular type of fragmentation or contract work-splitting leading to complex interfaces on LRTS projects, among national and international contractors in developing countries, is still unclear which is pivotal in devising an appropriate work-split while splitting the a single contract or carrying out work-packaging to avoid complexity at later stage. This paper presents a case study of an LRTS project in a developing country and focuses on the formation and implementation regime of complex interface formed as a result of particular type of contract work-splitting. The construction interface implementation regime in the light of challenges faced by the developing country forming the background and the IM issues involving multi-disciplinary, multi-cultural, national and international stakeholders are the foci of this study.

2. STUDY BACKGROUND

Lahore Orange Line Metro Train Project (LOLMTP) is the first Light Rapid Mass Transit System (LRMTS) project of Pakistan. The idea of the LRTS project came to life after a provincial urban transportation project implementation agency realized the importance of resolving the ever-increasing transport issues in the densely populated city of Lahore. Accordingly, it was decided to pursue LOLMTP as part of a long-term plan. The project comprised of approximately 27.1 KM stretch that runs through the heart of Lahore along Multan Road, McLeod Road & GT Road included elevated viaduct of 25.4 Km with 24 Elevated Stations and

1.72 Km of Cut and Cover section with 2 Underground Stations & one Depot and Stabling Yard in North to South direction as shown in Fig.1.

2.1 Formation of Complex Combination Construction Interface:

In consideration of the lack of finances and technical expertise of the local engineering bodies towards the complex electrical and mechanical (E&M) works involved in the project, international indirect stakeholders were engaged to finance the project and direct stakeholders (EPC Contractors) were engaged to execute the project. It was an understood fact at that stage that all the civil works will be per the concept design provided by the international EPC contractor and subsequently all the E&M systems equipment was to be procured by the international EPC contractor from its country of origin and were also to be in accordance to their standards. Thus, the overall construction period from commencement to taking over phase, of the EPC contract was taken to be of 27 months as proposed by the EPC contractor during bids. Conversely, while undergoing the negotiations phase, it was established that the selected international EPC contractor was deemed to be oddly challenged due to the unfamiliarity of the international contractor with local geological conditions, local norms of construction, and local market. Therefore, the civil works including the design and construction of works of the project were sublet back to the employer through an addendum and were to be executed under a separate agreement. Subsequently, the civil works were contracted as deposit work to a local government executing agency by the client department, which was further sub-contracted in 4 Packages to 4 different local civil works contractors under separate contract arrangement, as shown in Fig.2. The planned duration of the overall project was kept locked the same as in the EPC contract. However, the civil works contracts were based on item rate and comprised of 10 months duration including the primary structure works and the finishing activities. Whereas, the cumulative interfacing period i.e. time of interface construction for all packages was 9.6 Months among the civil and E&M works contractors from the 27 months, as shown in Fig.3.

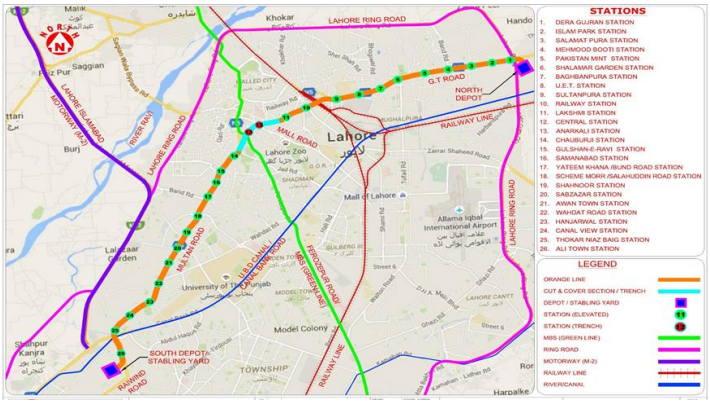

Fig.1. LOLMTP Location Plan (31.584426, 74.440756 - 31.457947, 74.238959)

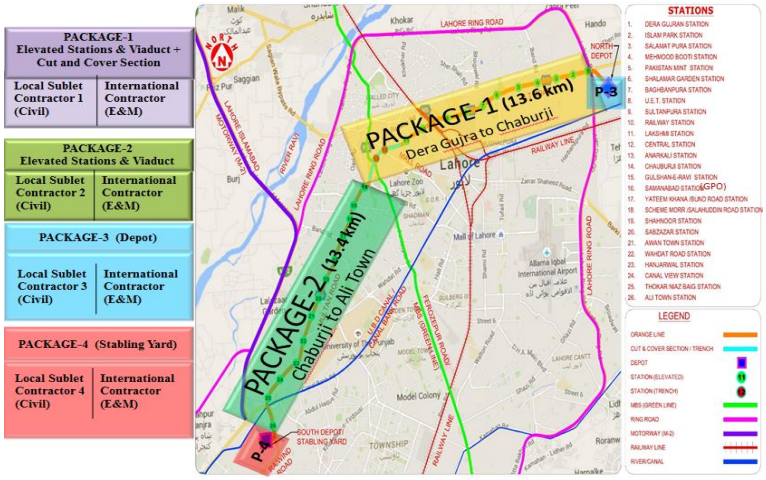

Fig.2. LOLMTP -Splitting of civil works Packages and Interfacing Timeframe

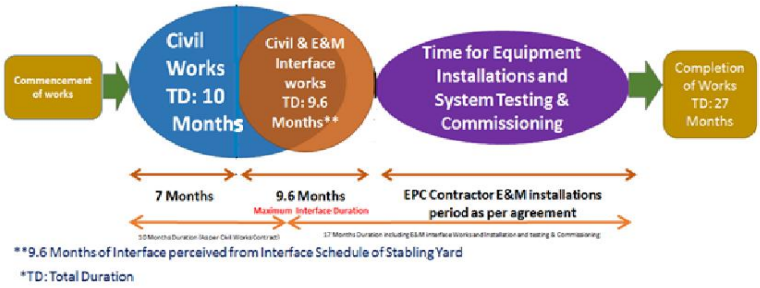

Fig.3. Interfacing Timeframe

The sublet civil works were to be executed as Employer designed works and a local Project Management Consultant (PMC) was given the task to design and supervise the civil works. This was also a unique practice, as in most cases the design and engineering services are entirely carried out by the secondary international contractor [49]. Whereas at LOLMTP the E&M design was to be carried out by the international EPC contractor, and the civil works design and specifications were entirely prepared by the local PMC. Furthermore, the concept design of the international EPC contractor, for which the Building Information Model (BIM) was available, was rendered inapplicable due to the subsequent designing of civil works as per site by the PMC. Moreover, due to the political enthusiasm of the government of both nations to commence the first project of such framework, the civil works commenced in fast track nature before finalization of E&M design by the international EPC contractor, therefore, the implementation of BIM techniques at fast track pace was also rendered inapplicable, which is considered vital for effective IM in modern-day complex projects [27, 50].

The assignment of deposit work of civil works including the primary structure works and the finishing items resulted in the formation of a complex work-split leading to an inevitable complex form of interface. This complex interface involved the contractual bifurcation of civil works finishing items and E&M works and the physical bifurcation of the contact points or otherwise, boundary activities of civil and

E&M interface works between the parties i.e. the international EPC contractor and civil works contractor of each package within the stations, depot and stabling yard buildings. Moreover, it was different from the typical physical interface as shown in Fig.4, and referred to as a combination interface as it involved real-time national and international stakeholders of multicultural, multi-disciplinary nature to execute the boundary activities, between the civil and E&M works within the same building and at the same stage as shown in Fig.5.

All these factors made the model different from the usual fragmented projects due to such complex work-splitting that major interfacing activities of the international EPC contractor were depending on international procurement, the unusual splitting of design, and the fast-track timeframe for the integration of both civil and E&M design and foremost absence of modern technologies like Building Information Modeling due to the splitting of design and parallel fast-track execution of civil works. To mitigate the uncertainty, the international EPC Contractor formed an interface document for the execution of integrated interface works between civil and E&M works which was signed with the Contract Agreement. The Interface document laid down a basic skeleton or work breakdown structure for the execution of the complex combination interface activities and thereby bifurcated and allocated, the responsibilities regarding the execution of boundary activities of civil and E&M works accordingly. The Interface Document (ID) provided 18 nos. potential interface events for the physical interface between the local contractors and the international EPC contractor and the physical interface heads in the ID were further sub-divided to form interface tasks and activities as shown in Fig.6. Each interface head encompassed a separate system for which the E&M contractor had separate teams which were to interface with the finishing activities of the civil contractors at the same stage.

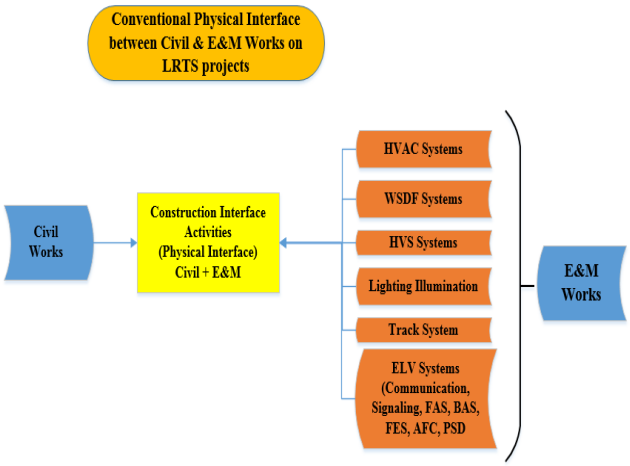

Fig.4. Typical Physical Interface of civil and E&M works

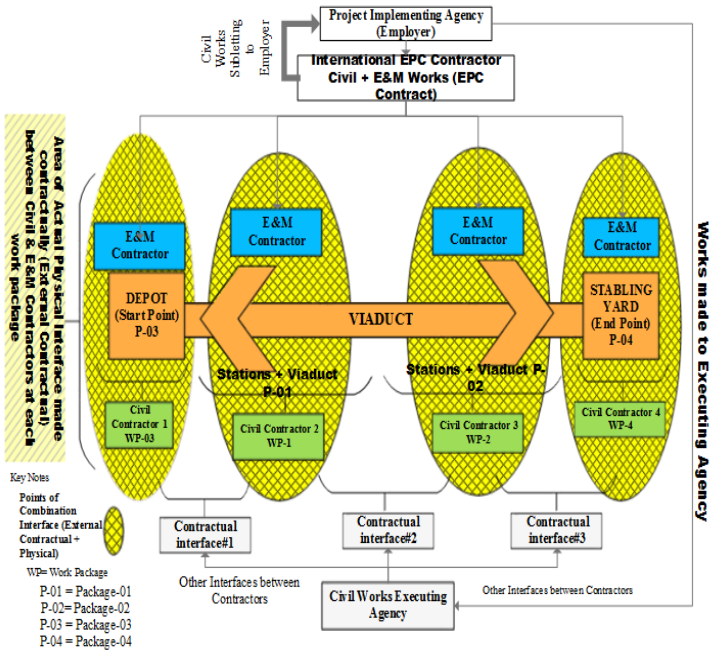

Fig.5. Complex Combination Interface Executed at LOLMTP

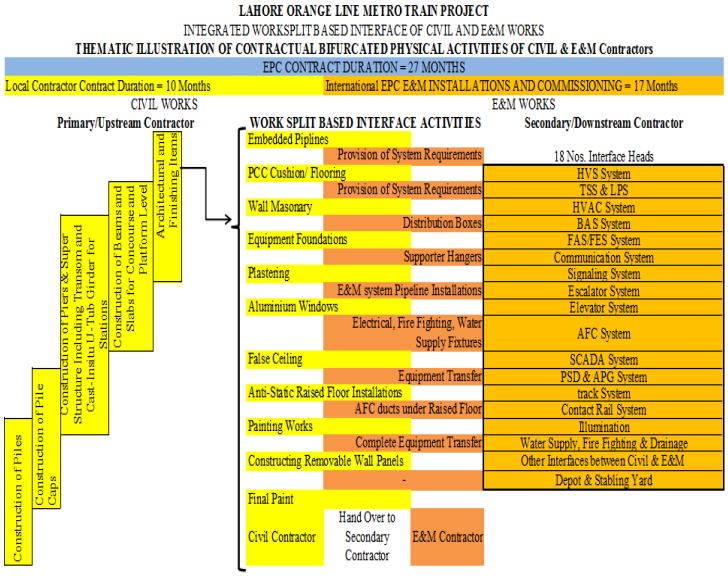

Fig.6. Interface Heads and Interfacing Activities

3. RESEARCH METHODOLOGY

3.1 Research Objective

There is a need to integrate the difference of Interface Management (IM) in developing countries on mega projects in consideration of the different dynamics of the industry of these countries. Moreover, the current related literature focused on interface problems. In the related literature, the studies focused on just examining interface problems as encountered in the mega-complex projects and their root causes and thus devised interface identification and resolving

techniques. However, in developing countries, the core of interface problems is fragmentation or contract work-split, whereas, multiculturalism due to the involvement of international contractors and the technological constraints further causes adversaries in developing countries. Therefore, there is a need to identify the core issues of certain contract work-split while involving international stakeholders by studying the interface implementation regime in developing countries. This research presents a case study whereby the IM issues are presented after a thorough study and critical analysis of the entire interface formation and implementation regime from the contract work-split phase. The pursuit is to chalk down the core IM issues in a developing country as caused by a particular type of contract work-split in the light of the constraints of a developing country.

3.2 Research Design & Case Description

The research design is based on a single case study based model of the Lahore Orange Line Metro Train Project. This method is adequate for addressing such research problems that require a detailed understanding of particular phenomena. This is because of the richness of the data that can be collected in a case study context [51]. The study considers the interfacing activities as Interface Points (IP) and then applies the cause and effect approach on the under consideration IP to identify the underlying IM issue as root cause. This method is used when there are numerous causes of a single problem [52]. The identified issues are summarized and then analyzed with the published body of knowledge through 'critical analysis'[44, 53] to form up the unique issues resulting from a particular contract work-split in a developing country involving multi-cultural and multi-disciplinary stakeholders.

The interface document for Lahore Orange Line Metro Train Project as provided by the international EPC contractor was interpreted in the form of interfacing activities of civil and E&M works on the construction interface plan. There was a limitation regarding the understanding of different planning & scheduling software in use by the local civil and international EPC contractor. So, the software for interface construction planning, scheduling, and communication planning was majorly Microsoft Project® and Microsoft Excel ®. The interface construction plan was prepared on Microsoft Project ®. The illustration of the interface plan for stations as shown in Fig.7 was the same for carrying out interface works at depot and stabling yard buildings. This study takes into account the interface construction plan of a station based on the methodology shown in Fig. 7 to investigate the IM issues in developing countries under a particular type of contract work-split involving national and international contractors.

The contractually bifurcated physical interface of civil and E&M works as shown in Fig. 7, where looks more like any typical interface, is quite complex when the actual WBS of the stations, comprising of two levels i.e. Concourse and Platform involving intense interfacing between civil and E&M works, is taken into the consideration. The interface plan went under execution on paper after 17 months from the commencement of the civil works. However, there were certain pre-requisite to interface works were pointed out by the EPC contractor after the visit of stations. These interface requirements typically included the construction of emergency evacuation stairs from the concourse level to the ground level, the layout of brickworks (internal & external), demarcation of 1m baseline on columns, escalator and elevator columns, etc. Due to this inordinate delay, interface works commenced after 14 days from the official on the paper commencement date. During the interface construction phase, the interface construction plan was revised to introduce segregation among the interfacing contractors. The two revised interfacing methodologies as shown in Fig.8 & Fig.9 were adopted as preventive IM methodologies.

Though the purpose of the revisions of interface methodologies was to introduce more segregation to reduce the interfacing points as a preventive measure, however, the persistency of the IM issues raised questions to contract work split among the contractors. The last elevated station was taken up for execution of interface works after 7 months from the actual commencement date. The interface construction plan for stations was delayed around 2 years after the initial commencement of interface works which were planned to be completed with 4 months duration. A comprehensive data related to monitoring and tracking of site progress and delays during the period from 2017 i.e. from the commencement of construction of interface works at the elevated station of LOLMTP till 2019 i.e. completion of 95% of construction interface is acquired. Aside from other issues like court stay order impeding the work activities and other political issues directly influencing the project, the construction interface model among the contractors single-handedly delayed the project for 2 years.

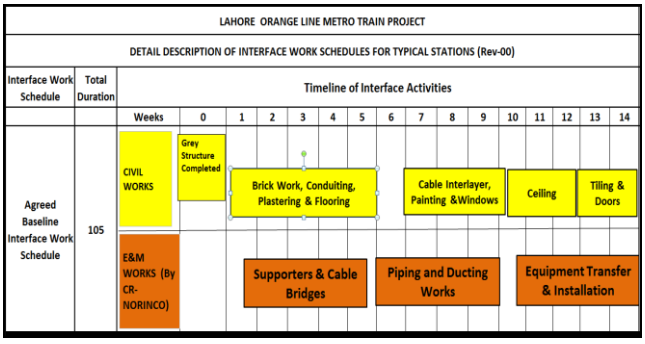

Fig.7. Interface Methodology with timeline illustration for Typical Elevated Station

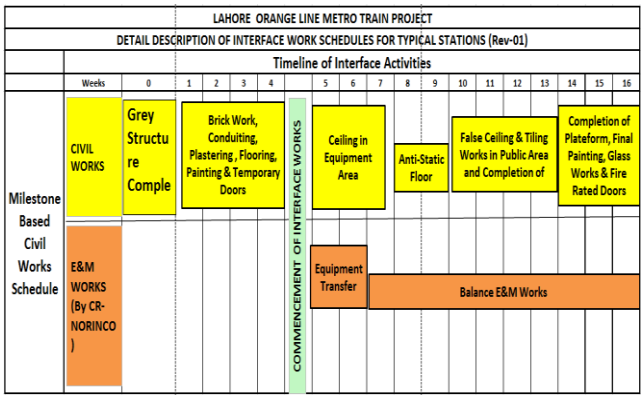

Fig.8. Revised Interface Plan Methodology (Milestone Based Interface Plan)

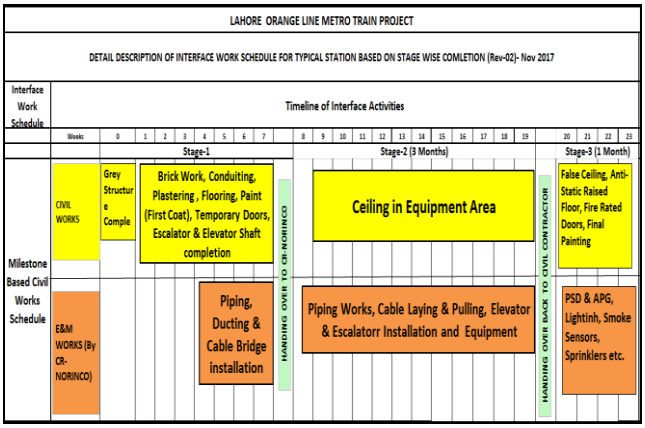

Fig.9. Stage Wise Completion Plan Methodology

3.3 Data Collection

The data including the interface construction schedule, progress, and delays were primarily collected from archival documents. The actual Interface construction schedule was acquired for Viaduct, Stations, Depot, and Stabling Yard. The actual interface construction progress and activity delays for the 2 years were taken directly from Microsoft Excel ® bi-weekly progress reports. The updates on the procurement schedule in Microsoft Excel ® for the E&M equipment were also monitored for its integration with the interface construction schedule. A member of the research team had been part of the project management office of the Project Management Consultant as interface scheduling engineer and was monitoring and collecting hands-on information and data on the dynamics of the construction interface.

3.4 Data Analysis

The contract-work split at Lahore Orange Line Metro Train Project was such that the interface works were bifurcated such as the main structure works and the architectural and finishing works were in the scope of the local contractor. Whereas, the E&M installations like piping, ducting works were in the scope of the international EPC contractor aside from the equipment installations. This rendered the entire finishing works of the local civil contractor e.g. false ceiling as part of interface works with the E&M contractor as shown in Fig. 10.

The delay at each IP is considered as the effect and the issues that caused the effect of delay are taken as causes. Primarily the delay causing issues are attributed to the respective contractors which are further divided into 3 types on a typical IP-based cause and effect analysis as shown in Fig.11. Direct interface issues i.e. the issues that are purely due to the interface between the Civil and E&M works for multiple teams e.g. work dependency issue, non-interface issues like court stay orders, and indirect interfacing issues i.e. the non-interfacing issues leading to direct impact on the interface point or only due to the formation of contract work-split leading to complex interface and may not be present otherwise e.g. the interface activity related international procurement of the international EPC contractor impeding the local contractor. The interface issues acquired from the cause and effect analysis of the interface points from all three interface construction plan methodologies are combined to form up a list of IM issues of LOLMTP.

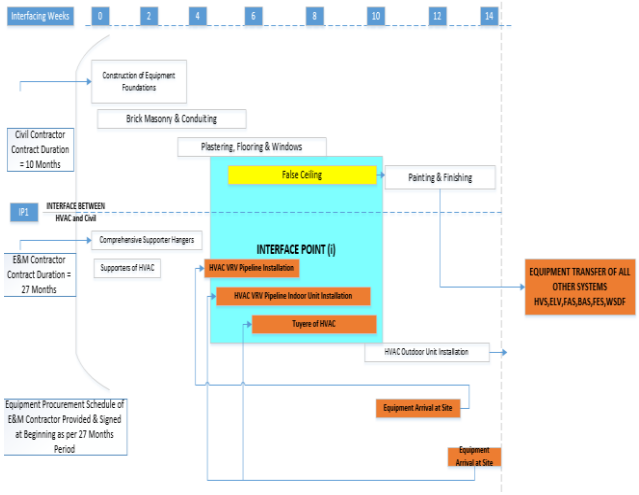

Fig.10. Typical Interface point of local and international contractors at LOLMTP

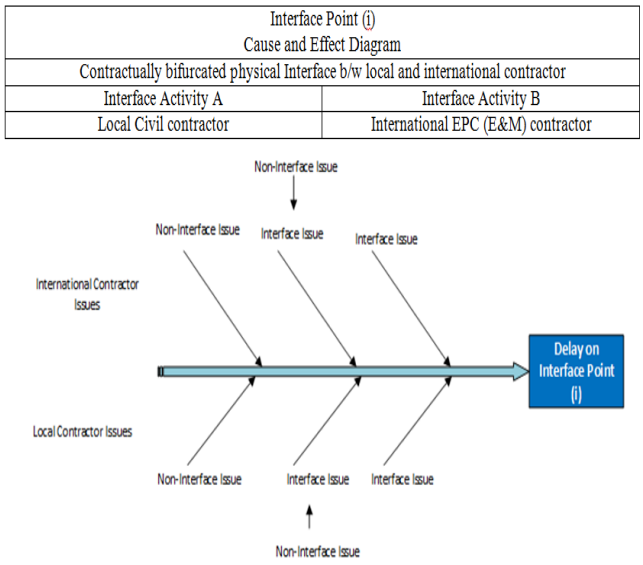

Fig.11. the Cause and Effect diagram to identify IM issue on Interface Point

4. RESULTS AND DISCUSSIONS:

The list of common IM issues as found out from the cause and effect analysis of interface points of the interface construction schedule of a station comprised of 11 major issues is compiled together in the order of revision of interface methodology to find out the persisting IM issue in all three interface methodologies as shown in Table.1. It was observed that 8 IM issues were found common even in the revised preventive construction interface plan methodologies.

Nevertheless, it was asserted that, aside from other issues, the prime factor of delay in execution of the interface works and the persistency of the IM issues was the combination model of the interface resulted due to the complex splitting of civil and E&M works boundary activities between the two Contractors from different origins and specialties working under separate contracts of different types. Furthermore, a 'critical analysis' of common interface issues of LOLMTP is carried out whereby the common issues in Table 1 will be compared with the interface problems found in similar literature due to contracts and the selection of different project delivery system models as shown in Table 2. The 8 nos. problems that are found out in the first column of Table 2 as a result of 'critical analysis' of interface issues of LOLMTP are the primary findings of complex combination interface issues of the current case study of LOLMTP. Whereas, the results and findings of the last column as shown in Table 2 after the critical analysis of the interface problems found in similar literature due to contracts and the selection of different project delivery system models are purely unique problems with respect to a developing country.

Table -1: Problems faced in Interface Construction plans at LOLMTP

Sr #	List of Issues	Initial Interface Plan Methodology	Revised Milestone Based Methodology	Revised Stage WiPlan Methodology	List of (Common) Issues faced in execution of complex split of civil and E&M works
1.	Delays in Commencement (Handing/Taking over) of E&M interface activities due to pending initial pre-requisites	✔	✔	✔	✔
2.	Non-clarity in the scope & sequence of interface boundary activities.	✔	-	-	-
3.	Significant Rectification/ Reworks by Civil Contractor due to revision in E&M design.	✔	✔	✔	✔
4.	Additional Requirements in E&M design on frequent intervals	✔	-	-	-
5.	E&M Procurement Delays affecting civil works	✔	✔	✔	✔
6.	Delay due to insufficient Manpower Resources due extensive level of mobilization inside buildings	✔	✔	✔	✔

Sr #	List of Issues	Initial Interface Plan Methodology	Revised Milestone Based Methodology	Revised Stage WiPlan Methodology	List of (Common) Issues faced in execution of complex split of civil and E&M works
7.	Suspension of activity of one contractor due to the working of others for indefinite periods	✔	-	-	-
8	Details of E&M works integrated activities were not available. (As per site Interface Construction Schedule)	✔	✔	✔	✔
9.	Other Contractor demobilized and comes after do his part and the required re-works and rectification	✔	✔	✔	✔
10.	Time & Cost Impact due to Additional Requirements to Protect sensitive E&M installations while other (Civil) Contractor is working	✔	✔	✔	✔
11.	Politically Influenced Changes	✔	✔	✔	✔

Table 2. Comparison of LOLMTP Complex Model Issues vs. Interface Issues arising due to Contracts from Literature Review & pilot study

Sr #	This Research (8 Items)	Similar Literature Reviewed Interface Problems identified	References	Unique Problems at LOLMTP
1.	Delays in Commencement (Handing/Taking over) of E&M interface activities due to pending initial pre-requisites	Interface Handover criteria to be made part of Contract Documents mentioning requirements	[10]	-
2.	Significant Rectification / Reworks by Civil Contractor due to revision in E&M design.	Reviewing & approval of designs by different authorities and failure to establish synchronization of civil and E&M design by Employer appointed designer divisions. Violation of Contract by damaging to already certified works of other contractors	[8, 10, 54, 55]	-
3.	E&M Procurement Delays affecting civil works	-	-	E&M Procurement Delays affecting Civil works
4.	Delay due to insufficient Manpower Resources of E&M international Contractor due to extensive level of mobilization inside buildings	-	-	Delay due to insufficient Manpower Resources of E&M international Contractor due to extensive level of mobilization inside buildings

Sr #	This Research (8 Items)	Similar Literature Reviewed Interface Problems identified	References	Unique Problems at LOLMTP
5	Details of E&M works integrated activities were not available. (As per site Interface Construction Schedule)	insufficient working drawings details insufficient specifications	[10, 36, 54-57]	-
6	Other Contractor demobilized and comes after do his part and the required re-works and rectification	-	-	Other Contractor demobilized and comes after do his part and the required re-works and rectification.
7	Time & Cost Impact due to Additional Requirements to Protect sensitive E&M installations	Change Orders and Variations	[36, 54, 55]	-
8	The interface document was missing a lot of details on interfacing	Unclear contract details and badly written contract.	[28, 58]	-

5. DISCUSSION

The unique problems of IM on LRTS Project in a developing country found after the post-implementation analysis at LOLMTP in the light of comprehensive literature review are the point of focus. This section aims to give insight on the IM issues with respect to the Interface Point (IP) and Interface Agreement (IA). Shokri, et al. [31] explained IP as a soft or hard contact point among different stakeholders on a project, whereas, an IA is an interfacing activity to be performed under a specific interface point. Ju, et al. [40] have used the term interface events for such interface points and similarly, the interface agreements correspond to the interface tasks. The purpose of adopting this methodology is to identify and bring forth the underlying cause behind a critical interface issue as part of this case study.

5.1 E&M Procurement Delays affecting civil works

Material procurement is planned at the beginning of the project [59], whereas, in some cases, concurrent planning and procurement are also taken into consideration [60]. The E&M international procurement delays of this model as chalked out in the last column of Table 2 are different in nature as these were due to international procurements and the due time-lapse had already been forecasted by the E&M Contractor at the beginning. All the E&M equipment was specialized and to be imported internationally (international contractor's origin country) which had an independent timeline provided by the E&M Contractor through its equipment procurement schedule. Whereas, this international procurement had a direct impact on the interface construction schedule of the upstream civil contractor. A similar example of such procurement-dependent IP has been shown below in Fig.12

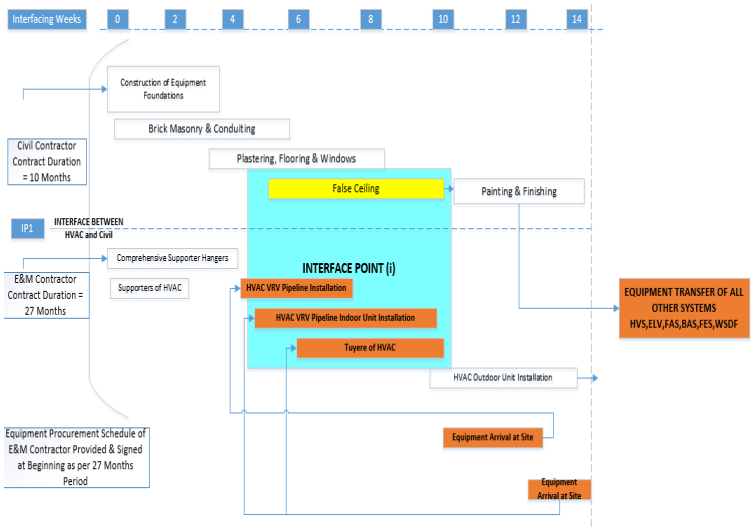

Fig.12. Procurement Dependent Interface Point

The activity of false ceiling at an elevated station concourse level public area and equipment area was to complete in the 10th week of the interface construction schedule by the civil contractor. The corresponding interfacing activities of the E&M contractor included in the Heating Ventilation Air Conditioning (HVAC) system was the Variable Refrigerant Volume (VRV) Pipelines, HVAC VRV Indoor Units Installation, and Tuyeres of HVAC. The planned procurement dates of the same material according to the procurement schedule provided by the E&M contractor, in accordance with the 27 months duration was starting from the 10th week of the interface construction schedule. This incoherence inadvertently delayed the false ceiling activity and along with this delayed activity of the civil contractor all the other subsequent activities with interdependencies like requiring continuous space availability were also delayed. It was perceived that this was primarily due to the incoherent integration of contracts i.e. E&M contract with the civil works contract which was under a stringent timeline under a different type of contract a phenomenon explained by researchers as fragmentation [10]. On the other hand, it gives rise to another type of interface interdependency as procurement-dependent interface points. Yeh, et al. [8] explained six types of interdependencies arising out of

interface works. Shokri, et al. [31] gave a simplified concept of such dependencies by giving five types of dependencies i.e. dependency of information flow, time dependency; space dependency, sequence of tasks; and physical/dimensional/functional systems dependency. The concept of procurement dependency on the interface has been new all along and requires to considered while the execution of such a complex combination of the interface. The physical interface contractually bifurcated requires a certain level of completion of E&M works at every stage along with the civil works so the delays in E&M procurement inadvertently affected the progress of civil works.

5.2 Workspace Dependency Issue.

This issue in other terms is described as one contractor stays demobilized at some section, site, and comes after to his part and the required re-works and rectification. Each interfacing participant requires a dedicated and continuous space to execute their activities and failure of the plan to incorporate the same causes delays and re-works [61]. The prime factor for consideration other than the complexity was to account for the parallel working teams of different specialty, origin, and working methodology of the local civil & international E&M contractor working under different contracts. The contractors at each package faced extreme difficulties in the execution of parallel interface activities even in the fully mobilized state due to closed confined spaces inside the buildings. This was considered primarily since the interface construction schedule of WBS Level-01 gave the overlap of activities but could not address the workspace dependency arising out of the interface also pointed out by Shokri, et al. [31]. Similar issues are addressed by modern techniques such as BIM 4D [61]. However, in the absence of modern techniques in developing countries and the case of LOLMTP due to reason owing to the work split as well, more effort towards IM and communications planning is required. Fig.13 below shows the interface point 'I' of Fig.12 from the perspective of being executed in parallel within an equipment room.

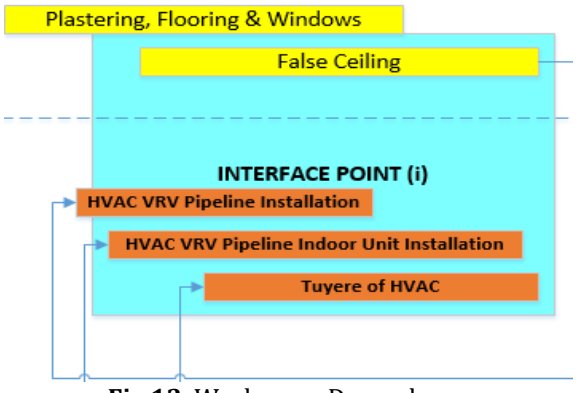

Fig.13. Workspace Dependency

This kind of overlap as shown in the above Fig.13 may provide the scheduling dependency but will not be able to provide the workspace dependency. Similar phenomena were encountered inside the equipment areas of stations and buildings when both the contractors were mobilized and working within their scheduled timeframe, but, clash in the execution of activities occurred inside a room as both the contractor were following the level-01 WBS schedule but there was not enough understanding and focus towards the as per site interface communication management plans or Interface Control Forms (ICF) [4]. Issues like demobilization of one contractor in order to provide workspace for the other cause inordinate delay on the timeline of the first contractor in case of inherent contracts. However such issues are majorly because of the lack of common values and objectives among the interfacing contractors [40]. Mousli and El-Sayegh [22] have established that traditional project delivery methods of design-bid-build are also partly to blame in this regard.

5.3 Insufficient Manpower Resources of E&M International Contractor

A unique delay that was not foreseen but it became a reality with time, that aside the laborers which were local, the specialized E&M works teams of the international contractor were scarce and also scattered around the project site. Therefore, these teams were never able to be in-step with the interface works schedule of civil works. This inadvertently caused delays in civil works as well which were suspended due to delayed E&M works. However, this delay was at the E&M contractor. Such issues were primarily caused due to the particular type of contractual splitting of works under inevitable and unavoidable circumstances resulting in the complex combination of interface between multiple national and international stakeholders.

5.4 The Complex Work Split Issue

The most pivotal point to consider here is the fragmentation or splitting of works i.e. civil and E&M activities among national and international contractors of multi-disciplinary teams working under incoherent contracts, as it occurred in LOLTMP. Mousli and El-Sayegh [22] have pointed out that the main problems in the construction industry are due to its fragmentation and lack of coordination among the contracting parties. Yeh, et al. [8] have recommended minimizing the construction interfaces in such projects by using preventive interface design methodologies that would minimize the interface points.

5.5 Other Common Issues

The actual completion of the interface for the most advanced stage station came out to be after 14 months from the original commencement date. Similar situations and issues were faced inside the buildings of the depot and stabling

yard. Whereas, in the viaduct, some of the scope of works like installation of cable brackets for HVS (High Voltage Supply) & ELV (Extra Low Voltage) systems, was transferred to the scope of the civil contractor due to the clarity in the interface document, which resulted in major cost increase of civil works as well. Moreover, a quite common phenomenon of delay in handing/taking over of interface activities by the upstream contractor to the downstream contractor was observed. This can be addressed through the incorporation of detailed interface handing/taking over criteria for each interface activity [10]. The additional requirements and measures to protect the sensitive E&M equipment and installations from the subsequent construction works of Civil Contractors was due to the insufficient planning at the early stage. Eldakdoky [4] supported the stance that such additional requirements were errors in the planning of interface and could result in extensive delays and additional costs. issues like political influence changes could be minimized if the regulatory body does not adopt a political approach in complex engineering projects [36].

These common issues found out as primary findings along with the unique issues as elaborated in Table 2 will add unique issues to the body of knowledge, pertaining to the projects in developing countries. This will also lay the foundation stone in identifying the key issues and focus points of IM for the international firms which are interested in working with the governments of underdeveloped countries in executing such complex projects in such handicapped situations. Furthermore, this will also enable researchers to devise preventive design construction interface methodologies such as complex contract works-split, forced under inevitable conditions, just like the same has been done considering the preferred Design-Build contracts [8]. It will also guide in the selection of the appropriate type of contracts, keeping in view the previous studies on benefits of each type of contract like EPC [32], DB [8], or BOT types [62], with multiple parties while keeping in view the limitations and laws in developing countries.

CONCLUSIONS:

This research performed a detailed case study-based analysis of the interface implementation regime of construction interface in a developing country involving national and international stakeholders working under a complex contract work-split at an LRTS project. The interface issues found in the study of LRTS project are unique e.g. impact of international procurement on interfacing activities, workspace dependency issue, and the knowledge of such (IM) issues is essential in replicating the same or different complex combination models under similar circumstances on LRTS projects. The root cause of interface issues is the complex work split of civil and E&M works involving multi-disciplinary local and international contractors working under incoherent contracts with uncommon objectives. Knowledge of IM is still in its adolescence in developing countries and other financial and technical constraints make the projects a lot more complex, therefore, more work and lessons learned are required to form up a knowledge base for the professionals in developing countries. The knowledge regarding the impact of contract work-split formation on Interface Management (IM) exists as a knowledge gap in developing countries and especially on LRTS projects and the findings of this study will assist in devising the right contract work-split based preventive construction interface methodologies at the planning stage while selecting the PDS for local and international multi-disciplinary contractors.

DATA AVAILABILITY STATEMENT:

Any data related to this article will be available on special request to the corresponding author.

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