"Designing and interfacing the Tunnel Ventilation System in Doha Metro Project. The value of BIM in MEP systems coordination."

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ABSTRACT

The aim of this paper is double:

1) To generally explain the TVS Design Interfacing discipline organization based on the TVS equipment to be implemented.

2) To transmit some of the advantages of applying BIM as a 3D modelling platform in the design of a massive infrastructure project versus traditional design systems, from the early steps until its total implementation.

Keywords: metro, design, interface, construction, installation, multidisciplinary coordination, clash detection, 3D modeling, BIM.

1. INTRODUCTION

Doha Metro Project Phase I is the most challenging recent TVS Project in the world including a short-time execution package consisting of: integral design, manufacturing, transport, installation and commissioning which covers all the underground stations (and some other specific locations) distributed along the four new metro lines.

One of the biggest challenges of this fast-track Project, was the extremely-tighten schedule due to the vicinity of the incoming FIFA World Cup 2022, which is the main motor of most of the successful civil developments recently addressed in the State of Qatar.

Design-and-build option was chosen in order to reduce the Project delivery. Hence, Civil construction took place simultaneously to the process of the MEP package design, interface, manufacturing, installation and commissioning. An intense multidisciplinary interfacing process involved the coordination of Project stakeholders, local authorities and the design production teams belonging to the main actors: Civil joint ventures, subsystems contractors (TVS, Energy, Signalling, Telecommunication and Security System, Platform Screen Doors, Rolling Stock, Railway Yard and HVAC systems) and other electromechanical systems.

Therefore, at the earliest stages of the Project there were no "as-built" drawings to work with. The only available designs where reduced to primary construction drawings that needed to be cyclically redesigned and coordinated between the abovementioned actors. At the beginning of the TVS Design Stage, many of the work sites where in an incipient construction phase and most of them not even under excavation, so adapting to the site conditions was not an option either.

2. TVS INTERFACE MANAGEMENT IN DOHA METRO PROJECT

The concept of Project interface can be defined as: "*The boundary between two (or more) parties or systems involved in a project*". There is an interface between two or more parts when one of them (Lead) needs for its conception or realisation to take account of inputs from another party (Partner).

Interface Management is the discipline which involves the resources, processes and tools to ensure that all relevant specifics about these touchpoints are addressed and shared in a consistent, timely and efficient manner.

Building collaboration lines and a fluid communication with other concerned participants was a difficult challenge to be addressed in each case. Documenting interfaces and providing solid communication allowed the different contracting parties to be aligned and helped to establish clear lines of responsibility and scope whilst bridging the space between them.

BIM implementation as an interfacing working platform was mandatory for all the Project contractors. As an outcome of the Project, it can be evaluated as an efficient tool for obtaining an accurate feedback, reliable information and a prompt analysis of the designs coordination conflicts in order to establish clear work guidelines for solving the arising issues.

The main profit obtained was an overall project improved performance and the limitation of costly mistakes and reworks occurrence. Successful interface management led to the avoidance of time-consuming disputes, guaranteeing complete understanding of, and agreement with, all decisions regarding project interface issues.

2.1. Interfacing levels

Depending on the contractual relation binding all parties involved in whatever interfacing matter related to Doha Metro Project Phase I, two interface levels which affected the TVS designer, manufacturer and supplier[1] (from now on, TVS, as part of the MHI[2] subsystems package) can be distinguished:

a) Level 1. External interfaces

   a. Between TVS and any external party with no contractual obligation regarding Doha Metro Project or TVS, such as other Projects' Contractors, Companies and (not restricted to) local authorities.

b) Level 2. Internal interfaces

   a. Between TVS and any other party belonging to the MMHKT[3] consortium except MHI (Mitsubishi Heavy Industries), such as: Mitsubishi Corporation, Hitachi, Kinki Sharyo and Thales and their subsequent contractors (Trackworks-TEL, SCD, SIG, AFC-Rolling Stock).

   b. Between TVS and any other party belonging to the following subsystems contracts, supplied by MHI (Energy & third rail-Platform Screen Doors).

   c. Between TVS and any of the Civil Contractors.

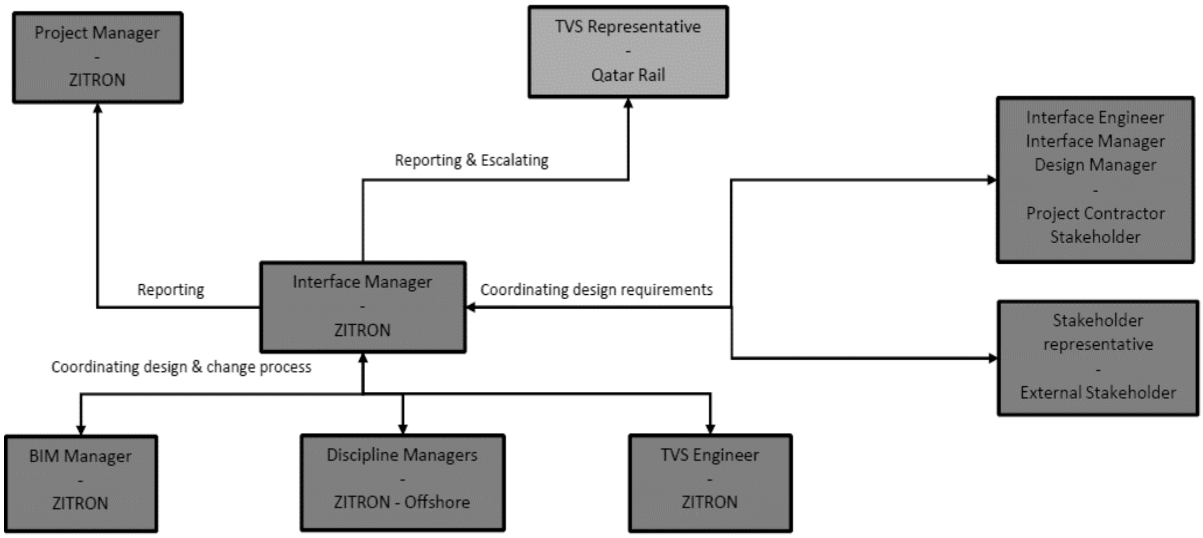
Each interface process was controlled and led by the concerned Qatar Rail Company (QRC) Departments and their Project Management and Control leads. Throughout the project lifecycle, each contractor was responsible for all its activities from design, interface, procurement and construction/installation to commissioning and the handover of the Project to the Client, QRC.

However, assuring a proper integration in the overall design fell on the responsibility of The Engineer (QRC final representative). In case that the interfacing process would be unsuccess and coordination between parties would have ended in a non-agreement or dispute, the issue

[1] Zitron is the TVS designer, manufacturer and supplier of a full package contract under MHI
[2] MHI is Mitsubishi Heavy Industries, part of MMHKT Consortium
[3] MMHKT is the Consortium awarded with the Doha Metro Project Phase I turnkey Contract for the systems package and it is formed by: Mitsubishi Heavy Industries (MHI), Mitsubishi Corporation, Hitachi, Kinki Sharyio and Thales.

would be escalated to The Engineer's arbitration and decision. This undesired solution took place just in few isolated cases (0.5% of the TVS design discussed matters), what is self-explanatory of the high level of success of the Interface Management process.

2.2. Interface team main roles and responsibilities



2.3. Scope of works

The TVS interface scope of works (SOW) involves a large list of equipment to be implemented at 42 underground locations, such as: metro stations, tunnel sections, stabling yards, mid-tunnel ventilation shafts and switchboxes.

As a summary, the below list of materials has been supplied:

a) Fire rated (250°C per 2 hours) mechanical equipment:

- Axial fans -158 Nos.-
- Noise attenuators – 312 Nos.-
- Diffusers – 312 Nos.-
- Jet fans - 116 Nos.-
- Air handling units -83 Nos.-
- Motorized smoke and fire dampers – 1024 Nos.-
- Volume control dampers - 30 Nos.-
- Sliding plate dampers – 2378 Nos.-

b) Fire rated (250°C per 2 hours) electrical cabling:

- Fire rated power and control cabling (250°C/2 hours) and its relative containment and trunking, up to 1400 kms throughout the Project.

c) Electrical and control equipment (up to 470 units):

- Distribution panels.
- Variable Speed Devices.
- Control cabinets (including Emergency Control Panels and Local Station Control Panels).
- AHU Soft Starters.
- Motor Control Cabinets.

The management of the TVS interface was successfully achieved by means of a wide engineering process in which any interface-related risk was analysed and controlled from the early stages of the project lifecycle with the aim of mitigating such clashes.

Considering the large TVS SOW, which is summarized in the equipment list mentioned above, it is not risky to account the TVS Design as the one which created the biggest impact in terms of coordination and in consequence, the most complicated to interface. The main reasons were:

- **Substantial space proofing requirements for equipment installation**. The size and weight of the equipment involved compromises its fitting and coexistence with other civil structures and MEP instrumentation/equipment (i.e., an average axial fan is weighing 15 tons and its dimensions are approximately 2500 mm x 4000 mm x 2500mm).
- **Equipment dispersion throughout the underground network**. At the stations, the equipment is installed in different technical rooms at all station levels (ground, intermediate, concourse, platform and underplatform). In tunnels, the equipment is mainly located at the station track area, tunnel portals and switchboxes. Cable routing coordination also affected tunnels, station corridors and other technical rooms. Such equipment dispersion created a big variety of different clashes and interfaces to be solved.
- **Constraints related to the equipment delivery routing**. Complicated and customized delivery routes (station wise) were faced due to the equipment dimensions/weight and its dispersion throughout the underground network. Safety at works was also a big concern, hence top detail interface documents -considering all the necessary measures and methodologies to be followed- was highly requested.

3. BIM IMPLEMENTATION ALONG THE SUBSEQUENT DESIGN PHASES IN DOHA METRO PROJECT

The BIM design was developed throughout different stages, progressing from very simple shapes for space proofing until high detailed designs incorporating all the equipment characteristics including MMS information.

The description of the different design stages in BIM terms were as follow:

1. **Design stage 1 (DS1)**: 3D model Level of Detail 100 (LOD 100). This level of design is used for space proofing and random cable connection route. Since the final dimension of the equipment can be not fully defined at this stage, and the main necessity is to incorporate all the assets in its locations to “book” the space, the shapes are simple now so the process of design is faster and the coordination is more agile.
2. **Design stage 2 (DS2)**: 3D model Level of Detail 350 (LOD 350). It includes 25% of the MMS data. The design is useful to confirm the required space in the different locations but starts approaching to the equipment final dimensions and geometry and includes some useful MMS information. The improvement in the geometry of the TVS equipment facilitates the incorporation of other services in the area such as third parties cable containment.
3. **Installation Drawings for Construction Phase**: 3D model Level of Detail 400 LOD400. The design is fully accurate including all the details of the TVS equipment. The cable routes are accurate as well and every item is identified. The space proofing is fully defined as per real workshop dimensions in order to allow the full coordination of other services at the same location.

4. **Mark-up incorporation** in the design to register as-build site real conditions.
   In this step, the drawings are modified according to the real installation that happened in the worksite. Measures are taken in each station and any equipment or cable route that had to be installed in a different way from the design perspective due to on site coordination with other services, is updated now in the Design.

5. **As-built drawings**. Level of Detail 500 (LOD500). Includes 100% of the MMS data. Once all the mark ups have been incorporated in the design, the As-built drawings can be generated. It includes truthful information of what can be found in the sites. Besides, all the equipment technical and commercial characteristics, codification and preventative maintenance tasks are incorporated for future maintenance management

4. BIM DISCIPLINE AND ITS ROLE IN THE TVS DESIGN INTERFACE

As explained in Section 1, the lack of As-Built drawings and finished structures forced a crucial interface coordination with the mentioned remaining parties in order to solve the Design clashes and deliver an integrated Design which guarantees a suitable manufacturing, installation and commissioning of the equipment according to the Project Schedule.

This massive interface coordination was requested to be done by means of a collaborative Design Project developed by dozens of simultaneous production teams belonging to different companies. The tight delivery schedule of the Project Design was only feasible by standardizing a 3D technology to be used by all parties involved: BIM.

BIM (Building Information Modeling) is an intelligent 3D model-based process that gives architecture, engineering, and construction (AEC) professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure.

By means of applying the BIM software in the project, all MEP designs quality improved and collaboration in real time allow to speed up the Project delivery process avoiding costly reworks. Besides the BIM performance as a Design platform, BIM is highly valuated for detecting clashes and/or conflicts between different elements of the Civil and MEP packages.

4.1. Clash detection

A clash is defined as the interference between different elements occupying in either way the same volumetric space within a combined multi-disciplinary Design model. A typical example of multiple clash happens in non-coordinated congested zones where several cable trays belonging to different systems are meant to be routed.

3D BIM Software incorporates a *clash detector tool* which is able to find, quantify and categorize any interference that could appear when considering several production teams working in parallel. This tool also eases the modelers and engineers' task of finding alternate solutions, if existing.

The clashes can be obviously detected with other methods by overlapping all the concerned designs, but such practice is quite obsolete, clumsy and uneconomic if we consider that this process is automated in BIM, which minimizes the human error while optimizing time and accuracy.

4.2. Clash types

Regarding the affection type and nature of the conflict detected, we can distinguish three types of clashes:

- **Hard clashes** are detected when two components are sharing the same space, such as a fire pipe running through a TVS lifting beam in a dedicated TVF room.
- **Soft clashes** are detected when the buffer zone, space proofing or tolerance of an element has been breached by another element.
- **Workflow or 4D clashes** involve conflicts due to unaligned Contractors scheduling and general workflow in different timelines of inter-disciplinary activities. This kind of clashes can consequently cause soft or hard clashes depending on the nature of the conflict, lowering the efficiency of the Project particular section since one clash can have a cascade effect on others.
- **Other types.**

4.3. Examples of BIM clash detection and different ways to manage the interfaces

a) <u>Hard clashes</u>:

<u>*Example 1*</u>*. Non-coordinated fire-fighting pipes clashing with TVF lifting beams.*

- *Introduction of the example*. The tunnel ventilation axial fans (TVFs) are installed at the TVF rooms over dedicated concrete plinths of an average height of 500mm. Due that the TVF average weight exceeds 10 tons, lifting beams are required to deliver and place the TVFs in position for installation.

- *Explanation of the clash*. The fire-fighting pipe designer and supplier did not coordinate its designs with TVS in BIM and directly proceeded to install the pipes before the TVF lifting beam was installed as per its own convenience. Therefore, the space reserved for the subsequent beam installation was invaded and the necessary space proofing for the fans delivery and replacement route was breached.

- *Solution and impacts created*. TVS equipment Design inside the TVF rooms was considered as the interfacing priority, since any potential impact was difficult to be absorbed. Hence, fire-fighting supplier was instructed to dismantle all the equipment already installed creating the impacts cited below:

  1) Obligation of extending the: requests for access to the TVF rooms, permits to works and occupation of the TVF rooms.
  2) Temporary blockage of other parties' construction schedule.
  3) Obligation to rearrange the coordination and interfacing in a correct way with the subsequent work iteration and delays related.

b) <u>Soft clashes</u>:

<u>*Example 1*</u>*. Correct coordination of the TVS AHU Nozzle design avoiding soft clashes with Rolling Stock.*

- *Introduction of the example*. AHU nozzles were implemented in the TVS design to steer the air jet provided by the AHU (generally located at a higher station level) towards the tunnel located downstream each station. Due to several factors such as: nozzle sizing, site space constraints and the train gauge space proofing, it was not possible to route the nozzles above the center line of the track, so they were generally relocated at one side of the track area with the nozzle nose obliquely facing the tunnel portal. The present case is one example belonging to the large list of soft clashes initially found between the TVS equipment and the Rolling Stock space provision.

- *Explanation of the clash*. As said, similarly to other TVS equipment (such as OTE/UPE ducts, sliding dampers and Motorised Smoke and Fire Dampers), the AHU nozzles were located in the station track area. Given that the train gauge space provision could not be invaded in any case, most of the AHU nozzle initial designs were discussed and requested to be relocated or redesigned in accordance to the space proofing restrictions and to the TVS Design requirements.
- *Solution and impacts*. Due that the clashes were detected in an early TVS Design stage, AHU nozzle could be adapted and redesigned considering the site constraints and the TVS design requirements. If this early interfacing would not have happened, plenty of man hours and additional expenses would have been necessary due to potential site reworks directly involving TVS and Rolling Stock and indirectly other third parties.
  Only considering the direct costs of dismantling a clashing nozzle, manufacturing of new pieces, installation of the new nozzle, commissioning of the AHU and management of the related works, savings can be estimated in the range of 5.000 to 10.000 USD per nozzle (as a reference, 84 nozzles were installed throughout the Project).

Given that AHU airflow and thrust were TVS design requirements of mandatory compliance, the nozzles sizing and injection angles (vertical and horizontal) needed to be customized and adapted to each particular site conditions.

c) Workflow clashes:

Example 1. District cooling pipe clashing with jet fans and/or obstructing the fan air discharge.

- *Introduction of the example*. In tunnels and switchboxes many linear equipment and services are located. Hence, different hard and soft clashes take place and services relocation is mandatory to allow cohabitation. In this example, hard and soft clashes were detected in a late design stage incoming from a workflow clash type. As per the official agreements between parties (TVS and Civil), the space provision for the Civil Contractor to route the district cooling piping at the top side of the switchbox section and for the TVS to install the Jet Fans at one of the switchbox side walls was coordinated by means of a signed Interface Control Form[4]. This signed agreement guaranteed that both services could live together without any adverse effect noticed and without any performance issue related.
- *Explanation of the clash*. After the abovementioned agreement signature, conditions were not followed and due to different timelines of the relevant parties during BIM coordination, district cooling pipe was moved to the same space provision where the jet fans should be placed. Furthermore, hundreds of cooling pipe meters were installed at site ignoring the ICF agreements.

  At this late stage of the TVS Design, it was found out that the updated BIM models showed the district cooling pipes clashing with the jet fans and in other cases obstructing the jet fan air discharge area, where an free space proofing should be guaranteed without the presence of any obstruction in order to maintain the fan performances determined by TVS Design Requirement and Specification.
- *Solution and impacts*: the final solution was to arrange additional investigations and reworks in order to solve this late clash, which had a difficult solution at such moment due to the actual congestion in the initially available spaces.

[4] ICF is the official document in which agreements, comments, drawings and mark-ups are reflected and signed by the interfacing parties.

1) Several interface meetings and hundreds of re-engineering hours spent to find a suitable solution to the clash.
2) Additional engineering works not planned, such as the collection of CFD analysis arranged by TVS with the aim of analysing the potential effects of the piping blockage over the jet fan performance and the potential mitigation measures to be applied under actual restrictions.
3) Relocation of the district cooling pipe by Civil where the clashes with the fans could not be absorbed or mitigated.
4) Installation of additional deflector plates by Civil to minimize the blockage on the air jet.

These impacts could have been avoided if the clashes would have been closely monitored and followed from an early stage. In this specific case, the different design timelines between the concerned interfacing parties determined the misalignment and in consequence, the so-called Workflow or 4D clash.

d) <u>Other types of clashes</u>:

<u>Example 1</u>. Clashes with potential safety consequences.

Hard, soft and workflow clashes can be also related to safety issues, such as a live wiring invading or nearly passing to a plumbing line, which can cause a short-circuit or issues with circuit completion.

One of the cases in which BIM was successfully applied to analyze and solve safety-related soft clashes in Doha Metro Project is explained hereafter. In this case, the safety-related clash was detected after design was finished, equipment installed and commissioning ongoing.

- *Introduction of the example*. As previously explained, the AHU nozzles were added to the initial TVS design to effectively help to blow the AHU air flow towards the tunnel located downstream each station. Due to the mentioned site restrictions and constraints, the nozzle noses were obliquely pitched to the intersection of the tunnel portal and the station boxes. The target was to keep the train gauge and other services buffer restrictions while complying with the technical TVS performance requirements.
- *Explanation of the clash*. The adapted layouts punctually caused an indirect safety issue when in few cases the air being blown towards the tunnels affected the egress walkway located at the opposite wall of the tunnel (fortunately, this issue took place only in 4 cases out of 84 along the Project).

  As per the applicable NFPA-130 standards, the maximum recommended air velocity in egress routes is 11 m/s, while in the mentioned cases the air velocity measured at the walkways exceeded this value. It must be mentioned and clarified that the affected areas were punctual and reduced to short walkway sections of 3 to 7 meters long.
- *Solution and impacts*. This topic was evaluated as a punctual but potential safety issue for evacuees in case of an emergency. TVS was requested to find a feasible solution without compromising the safe conditions in case of an evacuation. Several possibilities were evaluated but dismissed:

1) Installation of protective screens at the walkway edge.
2) Train gauge space proofing relaxation.
3) NFPA-130 recommendations relaxation.
4) Others.

Finally, after arranging a detailed nozzle re-routing study, adverse air effects were minimized or totally avoided by simulating the air jet projection[5] in 3D BIM according to different nozzle configurations case by case.

Mitigation reworks were necessary to be done at site (mainly related with the nozzle noses modification) in addition to the redesign reworks. Below impacts have been reported and absorbed:

1) Re-design and engineering works to be arranged.
2) Additional workshops, interface and coordination meetings.
3) Difficulties to obtain permit to works in track area at the related stage of the Project.
4) Night shifting, due to the congested working schedule in the track area.
5) Shifting and relocation of dedicated construction teams and resources.

5. SUMMARY AND CONCLUSIONS

For the referred Doha Metro Project, Zitron as TVS Designer and Supplier employed a highly skilled Interface Team involving a multidisciplinary workforce formed by Civil, Mechanical and Electrical engineers and specialists with the necessary support of a wide BIM Team composed of specialized engineers and modelers. The high performance, flexibility and problem-solving mentality of the team made possible to successfully incorporate and deliver the Tunnel Ventilation System Design on a timely and due manner.

BIM software applied to Doha Metro Project implied that every party involved was working in the same 3D environment, sharing information in real time and coordinating their activities in the virtual space.

Any modification from architectural or other subsystem designers could be detected in real time, which helped to improve each party's design implementation or to prepare the necessary information to be discussed in the interface meetings/workshops dedicated for solving the encountered clashes.

The success of the TVS interfacing process was achieved based on an estimated amount of 100.000 man-hours. However, these figures can be considered as an investment, since the estimated cost savings due to reworks avoidance is estimated in the range of 20.000 to 25.000 direct man-hours, without considering the effect and impact of any new-requirement materials fabrication, costs overrun due to own and others delays and the related penalties or back charges that could arise.

The experience found once the Project has been delivered is that the value added by this Design tool is not only extremely valuable in terms of cost savings and work quality improvement but necessary in the modern building projects in terms of "not to design in isolation".

Main advantages of BIM software implemented in the TVS design:

A. Improved collaboration and communication with third parties
   Cloud-based tools allow sharing Project models and coordinating between all design stakeholders
B. Improved coordination and clash detection
   BIM allows the early clash detection with architectural constraints or with other services running by common areas and facilitates the redesign to avoid the clashing on site.

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[5] As a design reference, the input considered for the air jet expansion angle in the 3D simulations was equal to 7.2 degrees, as per Idelchik's *Handbook of hydraulic resistance*.

C. Increased productivity and prefabrication
   Production drawings can be generated from BIM data, in order to prefabricated or stored materials in advance.
D. Pre-construction Project visualization
   Entire project can be visualized and modified during pre-construction phase minimizing expensive and time-consuming changes later.

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