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Analysis of public transportation system in makkah: Evaluation of efficiency, efficacity and safety operation of Almashaaer Al Mugaddassah Metro (MMMSL)

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Abstract

The pilgrim passenger service was designed to support traffic capacities of 72,000 pphpd (during Hajj), the line length is approximate 18 Km, double track, and standard gauge. This study proposes to evaluate efficiency, efficacity and safety operation of the metro system build in Makkah, Almashaaer Al Mugaddassah Metro (MMMSL). It is a special 18 Km of Metro line dedicated to support pilgrim service, especially during Hajj period. This line connects Arafat, Muzdalifah, Mina and Jamarat in Makkah area. This line was constructed in 2 years, during 2009 to 2011 time period, and entering in full service before Hajj, November 2011. This paper intends to suggest a further development(s) study concerning safety operation, and efficiency of the MMMSL metro line, and suggest potential infrastructure upgrades fit traffic capacities. Therefore, researchers present to the concerned reader(s) a paper structured to cater information for: introduction, line operation, dysfunctionalities, scheme development principles, identification of potential errors in scheme design, and recommendation for improvement. A qualitative research method was used, with both, literature review and five semi-structured interviews with industry experts. Research results indicated that more sample analysis and evaluation should be carried out, with a balance between a four-line metro system and upgrade the existing line to Maglev transport technology, software simulation of traffic capacities with verified software tools, analyse of station accommodation and loading / off-loading capacities, issues caused by signaling systems operating with OOP (Object Orientated Programming), etc. It was clearly outlined that existing metro system capacity cannot cope with 72,000 pphpd, and for existing forecasted figures of 2.5 million Hajj Pilgrims, a system with nearly 100,000 pphpd would satisfy requirements.

Keywords: MMMSL; Maglev; Hajj; Pilgrims; Safety operation; Scheme improvement

1 Introduction

MMMSL (2012) identified major components of a Metro / MRT system that include generally the following major infrastructure components: Metro stations are dedicated for passengers to enter and exit transport infrastructure. The stations may be an over-ground, under-ground and transfer (between different transport modes). The train depots will accommodate trains during non-operational works, and also, they are designated to perform regular maintenance activities, preventive and corrective. The Operational Control Centre (OCC) designated to run and control train operations. Some metro schemes may require a BOCC (Backup OCC) to be used in case of disasters such as major fire events, earthquakes, terrorist attacks etc., from where operators may take control and run train operation. Infrastructure connectivity between stations comprises tunnel, bridges and viaducts structures, transitions between at-

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grade to elevated sections. Other infrastructure component include building facilities i.e. traction power sub-stations, EEP (Emergency Egress Points), or other buildings as necessary to accommodate station or trackside's equipment.

In terms of Rolling Stock, maintenance trains and machineries in depot, the EMP (Electrical, Mechanical, Plant) to support functioning stations, and major structures such as Air Conditioning / HVAC, Lift & Escalators, Access Control System / Intruder Detection, Station SCADA, Fire Protection System, Low voltage & power distribution and UPSes, water and sanitation, facilities for travellers, etc. The MMMSL metro line was requested due to insufficient bus capacity, to transport pilgrims between Holy Mosque and Arafat. It was expected to support transport of 3.5 million peoples who arrive at Makkah annually to perform Hajj, with expected increase to five million, and resolve transport needs of local peoples and pilgrims during the heavy traffic congestion. This line was expected to transport 500,000 passengers in five to eight hours, hence reducing significantly the number of busses from 70,000 to 25,000. An effective and efficient metro system should prevent accidents such that occurred in 2006 at Mina, when 350 pilgrims died in a stampede (MMMSL, 2012).

The electrical lines were determined to connect different elements. First, traction power sub-stations, national grid, and the rail systems equipment such as signaling (CBTC, ATC, ATO, ATP, and ATS), telecommunication (Fixed, Mobile), traction power sub-station and TP-HUTs. Second, the power distribution along the track i.e. catenary system / HV connection between TP-HUTs, depot equipment, automatic fare collection, SCADA, maintenance management system, and platform screen doors. Finally, the track system, likely SGR (Standard Gauge Railway, 1435mm), and concrete encapsulated / plinth track or ballasted are considered (MMMSL, 2012).

2 Literature reviews

A standard design of a typical metro system which is developed for highly populated areas include: min. 350,000 to max 850,000 daily ridership, a rolling stock set, with initially 8 - 12 cars, 90 sec. headway, controlled from signaling system i.e. CBTC driverless, 90 km/h train operation. There are couple potential interesting schemes, developed for highly populated areas, with heavy passenger traffic i.e. Seoul Metro, Singapore Metro, Manilla Metro, New Delhi metro, Cairo Metro, Tokyo Metro, thy may be considered as part of further research, to evaluate solutions adopted, and quality of operation.

The Delhi Metro is an operational metro system with 351 Km of route, 10 metro lines, 255 Stations, 5 million daily ridership. Delhi Metro was the seventh busiest metro system in the world with 1.79 billion annual ridership. It commenced operation in 2002, modern system equipped with quality trains, air conditioning, contactless tokens instead of the paper tickets used in buses, escalators at stations, clean platforms, and convenient passenger information system provided great relief to daily commuters. The Delhi Metro Rail Corporation Ltd. (DMRC) was registered in May 1995 as a joint venture between the Ministry of Urban Affairs and the Government of the National Capital Territory of Delhi (GNCTD) to implement and operate the metro project (*Chandrorkar, 2021)*.

The Cairo Metros operated by Egyptian National Railway (ENR) and NAT (National Authority for Tunnels), and transported up to 3.6 million passengers per day. There are three main lines in operation, and further three planned for construction. The system has 87 Km length, yearly ridership is 1.31 billion passengers. Electrification system is 1500 V DC for metro line 1, and third rail for lines 2 and 3. Headway figures are 4min for line 1 and 3 min for lines 2 and 3. Line 1 is the busiest, with 60,000 pphpd and 80 Kmph operating speed (Railway Technology, 2021).

Tokyo Metro system is operated by the Tokyo Metro Company, Ltd., a private joint-stock company jointly owned by the Government of Japan and the Tokyo Metropolitan Government. It is a major mass transit system, with 9 lines, 179 stations, and 195.1 Km length. The annual passenger journeys are estimated of more than 2.2 billion, which makes Tokyo Metro between the densest metros in the worlds. Its daily ridership is 6.84 million passengers. Track gauge is a combination of standard gauge railways (1435 mm) with third rail power and are independent, and the rest of the network operates on narrow gauge (1067 mm). Its headway is between 3 to 6 min, and operating hours are 5am to 0:45am (COMET, 2021; Railway Technology, 2013).

2.1 Potential Causes

Based on the literature review, there are multiple causes for which simultaneously faults occurred on level 2, 3, and 4 (CBTC system architecture figure) such as incorrect design of the scheme, testing and commissioning, system acceptance, as they are abnormal for a metro system operating on a normal condition. A main cause is very short period allocated for project implementation (2 years), and likely insufficient time allocated for testing and commissioning phase (this normally last 6 to 9 months, with four distinctive stages.

Second, an alarm manual and alarm treatment for multiple SCADA system faults is delivered to the Client, typically there are 4 levels of warnings, and testing plan is developed based on this document to consider normal and degraded operation modes. Likely, this stage was not addressed properly. Third, insufficient training of station operation staff, especially for focusing on system failures. Forth, signalling system is tested on multiple levels, which include normal operational and degraded modes, likely they were improper performed.

Fifth, the equipment certification and testing of operating to local conditions of the project, this is normally done during step 3 – pilot track test period or track demonstration. Sixth, the RAMS study for introduction of axle counter technology to KSA and respective project was incorrect or not completed. Any new technology introduced in a country shall be verified with a specific risk assessment report. Finally, the equipment incompatibility, suppliers originating from different part of the world, standards lack of compliance. In this case, the technology selected for transport mode might not satisfy traffic requirements as established in the development studies.

2.2 Description of Failures

The faulty PEDC (Platform Screen Door Controller) at Mina - 2 Station is due to over-crowd, insufficient qualification of operational staff, which determine manual operation of signalling system (any fault of PSD controller will be transferred to STC. It will block the Automatic Train Operation / ATO); Faulty PSD at Mina – 1 and Mina – 2 Stations, SCADA system generated false alarms; Muzdaliffah 2 station traction power feeder MC-22 was tripped as it exceeded the load current settings. The sub-sectioning point TSS-11, MQ01 Q12 status was switching the status continuously between locked and unlocked. Also, the Passive VOBC at trains 1, 3, and 14 lost communications with VCC at the cross-border sections, while the Axle counter defective, ACE (Axle Counter Evaluators) could not be remotely cleared of signalling system and train detection. On the other hand, the rolling stock failures are considered such as doors operating manually, announcement not synchronized; Communication issues between Station (STC) and VCC (MMMSL, 2012).

2.3 Operation Issues

In 2015, around 2 million pilgrims performed the Hajj in the Holy City of Makkah. There were 2 major accidents that cause 1000 pilgrims died, and major criticism to Saudi Government for poor arrangements, lack of planning and safety. The metro system is a minor part of the Hajj operation, but crowd management is still a big issue. The pilgrims put their lives and others at risk, due to the fact they disobey authority's instructions, caused by impatience, anger, and improper behaviours. MMMSL should transport 0.5 million pilgrims from Arafat to Muzdalifah in 5 to 6 hours. Any occident may cause major malfunction of the metro system. A major accident costed more than 700 lives, may need several days to restore Hajj process, if occur, that will severely impact on all arrangements made for pilgrims (Pakistan Kakhudahafiz, 2015).

Saudi Arabia's civil defence said, on Thursday, 24 September 2015, at least 717 pilgrims died, and 863 were injured. There was a poor control of crowd control, and group of pilgrims collided, due to failure to follow with the crowd control rules. After the 2004 stampede, in which 251 peoples died, at the Jamarat Bridge in Mina, Saudi Royalties announced a major renovation project for Makkah. In 2006, 360 pilgrims were killed in a stampede in Mina (Channel4, 2015).

2.4 Qualitative Method

In assuming people and groups construct their social reality, a qualitative method drawn from the constructivist paradigm is appropriate to provide data in answering the research question (Denzin & Lincoln, 2005). Since quantitative methods allow for the collection of quantifiable data, examining relationships, standardization of reporting, and testing of theories, it was decided that a quantitative research design was inappropriate to provide answers for the research question of this study (Harkiolakis, 2017). Since quantitative data was not needed to answer the present research questions, a mixed-methods approach was also deemed inappropriate. Given that the study's purpose calls for a deeper understanding on how stakeholders of MMMSL may use superior transport technologies to attain support organizational transformation, an exploratory single case study with embedded units will be utilized to meet the study goals and explore a problem embedded in a complex social process (Bryman, 2017).

Constructivists aim to interpret interactions between the environment and the individual while challenging individuals to be more critical of their understanding of themselves and their world (Cooper & White, 2012). Qualitative research presents opportunities to gain a deeper understanding of behaviour within organizations and how to analyse business decisions; in the context of this study, this refers to how stakeholders of the MMMSL to support organizational transformation. Qualitative case studies uncover contextual, holistic, and in-depth knowledge by utilizing multiple sources of data and are an integral component of the business field (Eriksson & Kovalainen, 2015). Researchers can assess a specific case from numerous perspectives by utilizing a qualitative approach and multiple sources of data. A single case study investigating a social phenomenon can involve individuals living within a particular social context as embedded units of study (Bryman, 2017).

3 Methodology

3.1 Case Study

This case study proposes to evaluate efficiency, efficacity and safety operation of the metro system build in Makkah, Almashaaer Al Mugaddassah Metro (MMMSL). It is a special 18 Km of Metro line dedicated to support pilgrim service, especially during Hajj period. This line connects Arafat, Muzdalifah, Mina and Jamarat in Makkah area. This line was constructed in 2 years, during 2009 to 2011 time period, and entering in full service before Hajj, November 2011.

3.1.1 Infrastructure Layout

The route layout is given below. Basically, there are 9 metro stations (3 station groups), one train depot fitted with traffic control center (OCC), as shown in Figure 1. Length of trainsets 278m, 12 cars formation (A, B, C, and D car types), 3.10m width, 2.1m high, and all trainset can carry 3000 passenger/trains. There are 60 doors/side (5 doors / side / carriage), each carriage having 45 seats (MMMSL, 2012). The traction power is 1500 VDC with overhead catenary system, while signaling system is Communications-based train control (CBTC) with driverless automatic train operation (ATO), backup drivers in each train in case of failure. CBTC architecture and logical connections are explained below (MMMSL, 2012).

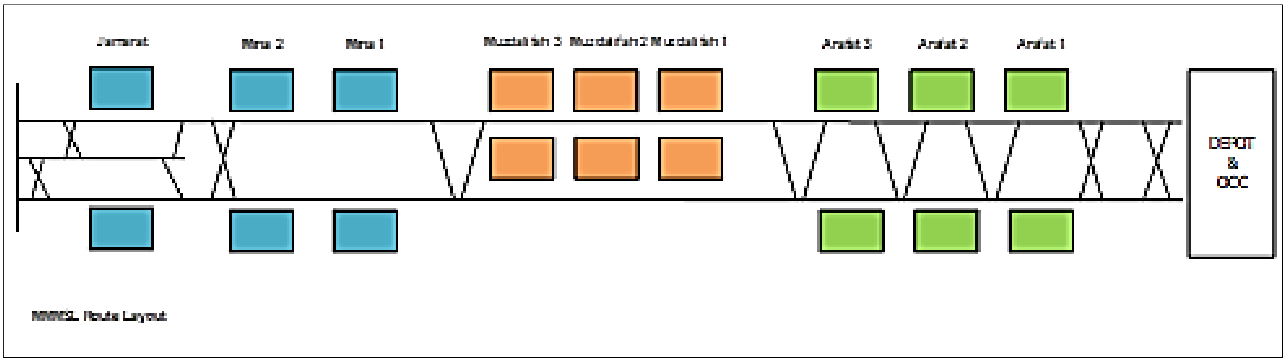

Figure 1 MMMSL infrastructure layout (MMMSL, 2012)

The track system was designed using SGR 1435mm width, a combination between ballasted and ballastless track (or track plinth), most of the route is elevated on viaduct, with turnouts and crossings. Rail type is 60 UIC, infrastructure designed to support max. 21 TAL (Tone Axle Load).

Power supply and catenary system include two transformer stations 110 KV to 13.8KV, 11 traction sub-stations to fed trains with 1500V DC, standby generators, catenary system. The signaling system based on CBTC architecture incorporates SMC (System Management Centre), VCC (Vehicle Control Centre), STC (Station Controller), VOBC (Vehicle Onboard Control) (MMMSL, 2012).

The CBTC System Architecture is designed as a block of flats with 4 levels. Level 1, higher authority is the CENTRAL (SMC = System Management Centre), which is equivalent to the Traffic Control Centre / OCC. Level 2, wayside system, is based on VCC (Vehicle Control Centre), which basically control a number of station and intra-station sections. Level 3, Station Level, contains STC (Station Controller), and PDIU (Platform Screen Doors Interface Unit). They control switching points, signals, Platform Screen Doors. Level 4: signaling equipment on trains, VOBC (Vehicle On-Board Controller). Each train has 2 x VOBC (VOBC-A, VOBC-B), one working and other passive (hot stand-by configuration), for redundancy.

The Safety Integrity Level (SIL) is a measure of performance required by a safety function. Level 2, 3 and 4 signalling equipment's are designed to SIL 4, probability of failure being the lowest, 10-5 (MMMSL, 2012).

The telecommunication system is made of fixed (data network, CCTV, telephony, PAS/PIS, clock, DVVR / event recorder), TETRA mobile networks, and SCADA. Platform Screen Doors (PSD) is provided to separate zone of station by track and protect peoples failing on track areas as shown in Figure 2 (MMMSL, 2012).

Figure 2 Platform Screen Doors (Thales, 2010)

The Platform Screen Doors are physical screen barrier located on the station platform preventing unauthorized access to the track. They control passenger flow control and provide emergency exit during trackside evacuation. Main designation is to improve passenger safety and comfort (cleaner, quieter, crowd control, etc.).

Secondary, they provide climate/environmental control, improves train availability, and enhance the architectural design of station platform (MMMSL, 2012). Stations buildings also are based on two separate architectural solutions: type 1 (Arafat, Mina, Jamarat) and type 2 (Muzdalifah) (MMMSL, 2012).

3.1.2 Infrastructure Operation

The train operation is protected by ATO/ATP/ATS and provided by Thales, Seltrac S40. The dwell time in station is 60 seconds while the headway regular metro service is 240 seconds and it is the average between trains in convoy (Hajj peak) is 150 seconds (MMMSL, 2012). In this case, the movement arrangements are depicted in the below Table 1:

Table 1 Operation Plan (MMMSL, 2012)

Code	**Movements**	**Day**	**Operating Time**	
			Start	**End**
A	Normal Metro all stations	7	00:00	24:00
		8	00:00	20:00
B	Mina 1,2,3 and Muzdalifah 3 - Arafat	8	20:00	04:00
		9	04:30	10:00
A	Normal Metro all stations	9	10:30	15:30
C	Arafat - Muzdalifah	9	18:30	23:30
D	Muzdalifa - Mina	10	00:00	10:00
E	Arafat 3 + Muzdalifah 3 + Mina 1 + Mina 2 - Jamarat	13	04:00	18:00

3.2 Research Method

The purpose of this qualitative, single case study is to describe how stakeholders of the MMMSL in Makkah may use alternative technology to a standard metro system to improve efficiency, efficacy and safety operation of public metro system, and address transport needs for Hajj Pilgrims.

In this case, information from a range of 5 semi-structured interviews, reflective field notes, and extensive archival data will be collected through multiple sources to obtain data to answer the study's research question (Stake, 2010; Yin, 2017). Triangulation of data sources will be utilized to establish the trustworthiness of the researcher's analysis and findings on the phenomena under study (Guion, Diehl, & McDonald, 2011).

Modernization and performance of MMMSL are significant for the economic development of KSA (Kingdom of Saudi Arabia). A deeper understanding of the challenges facing stakeholders may be significant to practice in informing stakeholders on the managerial competencies needed s to drive its infrastructure and organizational transformation.

Other alternative source of information would be literature review, based on project information database and projects implemented in other locations, with similar requirement, and developed with superior technologies.

3.2.1 Research question

The main question of this paper is, how do stakeholders of MMMSL may implement infrastructure upgrades to attain superior performances, both operational and safety, and organizational transformation needed to support required changes?

Sub-set of questions

- SRQ1: What technical solution may work better for a metro system in highly congested areas?
- SRQ2: How do you think a metro system would benefit of introduction of Maglev? Would Maglev be a more appropriate technology, in your opinion? Why?
- SRQ3: What are the main issues of standard metro system, based on conventional railways?
- SRQ4: How safety operation of a metro system may be improved to avoid accidence occurrence?
- SRQ5: What are the best technical solutions to manage crowds in metro systems operating in urban locations with high traffic demand?
- SRQ6: What organization changes might be needed for a metro system converted from standard railway to Maglev?
- SRQ7: What is the impact of transport solution change in operation and maintenance staff qualifications and skills?

3.2.2 Source of Data

Project database and accident investigation report(s), as part of the "Literature review"; Interviews will be carried out with experienced engineering consultants, highly recognized entities with the transport industry. Reflective/journaling field notes will be taken during the interview process.

Other potential sources are historical, seminal, and current peer-reviewed scholarly papers on the study topic. They may also include archival data information on industry and economic development reports on the GCC region, particularly in KSA.

3.2.3 Background of Referrals

- Ref#1: +15 years professional experience with construction industry, experience with Metro system, he held the position as Crowd Project Manager in MMMSL, educated to MSC / MBA / PhD (Candidate);
- REF#2: +20 years professional experience, civil engineering and project controlling, educated to BSC / PhD (Candidate), and held positions as Program Controller in several metro projects: Delhi Metro, Dubai metro, Riyadh Metro;
- REF#3: +15 years professional experience, civil engineering and project manager, Lecturer in the University, educated to MSC /PhD / PMP, held project management positions in MMMSL and Cairo;
- REF#4: +35 years professional experience, signaling & systems manager, business owner specialized in design of rail systems for standard railway and metro, educated to BSC Electronics, previously jobs as Head of Testing Laboratory Metro systems, design and testing commissioning services for UK Railways / Bucharest Metro / Istanbul Metro / Karabuk railway project in Turkey;
- REF#5: +35 years' experience, OAM / Safety & Quality Expert, educate MBA level plus several qualifications gained on safety and quality, work experience based in the UK (railway) and Saudi Land Bridge (KSA).

Selection of referrals was conducted on various criteria: multi-national team coming from different geographies and cultures, work experience in GCC region and/or congested metro systems, high education credentials.

4 Results and discussion

4.1 Referrals' Suggestions

All referrals suggested that MMMSL had several technical issues that may require further investigation and potential scheme upgrades. Operating issues of MMMSL might be caused by various sources: improper selection of transport technology, architectural design issues, operation plan, signaling system, PSD performances, and general technical performances of the system used, improper design, insufficient testing & commissioning, homologation of the system.

The signaling system CBTC is operating with CBI (Computer Based Interlocking) which are built on OOP (Object Oriented Programming) technology. Each infrastructure model requires re-modelling of software objects, individual OOP updates takes 2 to 4 sec, that introduce a latency on system operation. Alternatively, a signaling system based on PLC (Programmable Logical controllers) might operate at superior characteristics, and reduce dwell parameters.

The infrastructure traffic capacity was over-estimated, with technology adopted and operational model, MMMSL cannot achieve more than 45,000 pphpd (15 trains x 3,000 passengers). If the Client wishes to achieve more traffic capacity, a superior technology is needed, recommended parameters might be 60sec dwell time, and 60sec loading / offloading of passengers. Such parameters would enable increase of traffic capacity to nearly 100,000 pphpd, which is the existing Hajj Pilgrims visitor numbers (2 to 2.5 million/year). If the number of pilgrims will raise to 5 million, likely, a second system of Maglev should be constructed and there will be no bus services required anymore for the pilgrims services.

Referrals suggested the End-Client to use a development approach conforming with international standards and GRIP (Governance of Railway Investment Projects), which is a very powerful PMIF system. GRIP has identified 8 different stages differentiated to be followed for a successful project implementation.

This investment procedure is based on project management standards i.e. PRINCE2 (PMBOK could be used complementary, also, to complement PRINCE2 or even to replace, if necessary), British and International standards (many well-known international standards are generated by the UK Rail Industry).

Project based-activities are divided into 8 distinctive phases: Project Definition, Pre-Feasibility, Option Selection, Single Option Development, Detailed Design, Construction + Testing & Commissioning, Scheme, Project Close Out. Project preparatory phases (preliminary, outline, tender) are equivalent GRIP 1 to 4. Construction phase or design & built contract conforms GRIP 5 to 8. Deliverables are standard products fixed in templates, specific for each phase. It is heavily used by Network Rail (UK National Rail Infrastructure Operator) and LUL (London Underground).

The main features of this system are: clarity and consistency, pace, focus, relevance, assurance, efficiency, standardized approach and simplicity.

To evaluate efficiency and efficacity of the metro system, it is anticipated to re-visit documentation prepared by past consultants as part of GRIP2, produce a robust and well-referenced Option Selection Report, and prepare outline design for scheme upgrade (if needed).

4.2 Recommended Prevention System

To prevent re-occurrence of similar accidents, it is mandatory that the End-Clients or final receipt of infrastructure projects to ensure works are carried out conforming international standards and code of practice. Scheme developments should comply with international system adopted for PMIF (Project Management Investment Framework) i.e. GRIP from the UK or PMBOK + CENELEC EN 50126.

The selection of transport technology should be based on "Option selection" analysis, supported by CBA, to fit better local environment operating conditions. An accurate project controlling should be put in place, allocate sufficient time for production of testing & commissioning documentation and carry out site specific activities.

Other mandatory factor is to establish consistency and accuracy of the design, testing and commissioning documentation. System Integration between various components should be properly analyzed, identify obstruction such as standard differences. Staff qualification and competencies to be adequate for the selected system. Tools and equipment's to have certificate of use on similar past completed projects.

The procurement of equipment, equipment approval procedures to be well structured and aligned with further strategies for investments. Other factor, the end-Clients to instate a standard catalogues document, to be used commonly by the project with other similar to be developed in country. The testing and Commissioning to include a Pilot tests / Track test to be performed on the area of project to check suitability of equipment operating on local environment conditions.

4.3 Transport Mode Selection Principle

To recommend the appropriate type of infrastructure, the Consultant or the Client should use source, based on urban transport capacities calculation and evaluation. In this case, the Consultant or the Client should perform core activities that will determine type of infrastructure, as a complete evaluation is performed as follows:

- Step 1, to prepare traffic demand analysis, perform additional investigations: interviews, request for information from Government agencies concerning further economic development plans, improve of economic system. Determine more accurate figures for PPHPD and daily Ridership.
- Step 2, to evaluate traffic demand of the concerned geographic area.
- Step 3, to pay attention to station designs, identify construction constraints, access to station requirements, fire protection and evacuation.
- Step 4, to evaluate accommodation and maintenance capacities of train depot and OCC;
- Step 5, to evaluate impact of additional works on wet and dry utilities, identify construction risks working near-by or relocate.
- Step 6, to create a benchmarking model to existing railway transport in the region, and use of international best-practice model.
- Step 7, to evaluate network expansion in the future, consider making passive provision to easy enhance traffic capacities.
- Step 8, to revise more accurately conclusions on transport mode assessment.
- Step 9, to consider VE/VA (Value Engineering / Value Analysis) (as Option Selection / GRIP 3) based on CBA (Cost Benefit Analysis).

4.4 Benchmarking to Other Industry Products

It was also suggested, the End-Client consider to perform additional study to evaluate an improved standard metro/MRT system (perhaps 4-line operation), versus superior technologies such as Maglev. Another potential source of information includes urban transport schemes with high technical characteristics for operation such as Dubai Metro, Hong Kong MTR, and Vancouver Sky Trains.

An alternative technical solution is Shanghai Maglev Train Line, and other similar Maglev developments for urban transport (i.e. Changsha Airport, Hunan Province), to be identified. Shanghai Maglev Train or Shanghai Transrapid is a magnetic levitation train that operates in Shanghai, PR China, and connects Longyang Road to Pudong International Airport. Line length is 29.8 Km, a journey takes 7min and 20sec to complete the distance. Operational speed is 431 Kmps which is reached after 4min, while a train reaching 300Kmph needs 2min. Construction of the line starts on 1st March 2001, and entered in commercial operation on 1st January 2004, after 2.5 years of construction and running tests. The record speed is 501 Kmph. A maglev train has 153m length, 3.7m width, it can carry 574 passenger on a 3-class configuration.

4.5 Further Studies and Revision of Makkah Traffic Management Plan

Obviously, the MMMSL might require some further infrastructure upgrades, to cope with needed traffic requirements and safety operation. Further research should identify constraints of operation, and balance standard metro system versus newly technologies like Maglev. The additional studies shall re-evaluate technical parameters (traffic capacities, headway, and operation parameters), commercial (cost of upgrades), social and environmental implications. Some solutions will be balanced and appropriately selected with CBA (Cost Benefit Analysis). It is advisable that a more complex evaluation study to be performed, to investigate operability of the line, compliance of equipment's to traffic needs, capacity for expansion, allocation made to increase the capacity, and upgrade to superior technologies such as Maglev.

The MMMSL line terminates at Jamarat / Mina, about 5 Km distance of the Holy Mosque as shown in Figure 3. As the main traffic of pilgrims would flow between Holy Mosque and Arafat, if is expected MMMSL line to connect with newly planned metro system on a designated inter-change station.

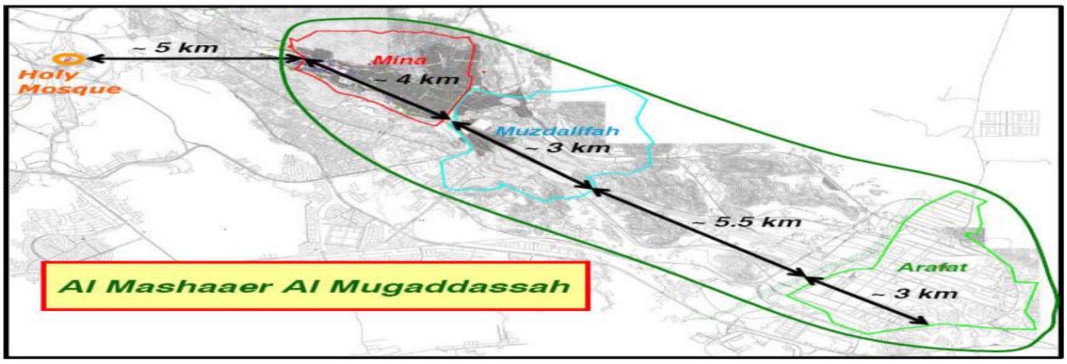

Figure 3 MMMSL aerial layout

This technical solution might lead to additional issues: inter-change station may become an additional congestion point, transfer of passenger may create additional issues i.e. safety, the cost of an inter-change station and construction risks are higher. Therefore, and as it is anticipated, the upgraded Maglev line should be extended up to the vicinity of Holy Mosque or even under, if allowed. The MMMSL line should be kept segregated of the newly planned metro system.

4.6 Consider Maglev as transport technology

Wilson (2021) states that Maglev uses magnetism, to levitate trains above the track. They are faster, more efficient and environment friendly than standard railway technologies based on wheel – rail friction. Trains based on Maglev technologies are faster, safer and more energy efficient. Daud (2020) stated there are two types of technologies in use: EMS (Electromagnetic Suspension) and EDS (Electrodynamic Suspension). Other technologies under development are Indutrack and MDS (Magnetodynamic Suspension).

The EMS uses the attractive force of electromagnets placed on the guideway and on the train to achieve levitation. The benefits of this method are that it is simpler to implement than EDS, and that it maintains levitation at zero speed.

The EDS uses the repulsive force of (superconducting) magnets placed on the guideway and on the train to achieve levitation. The magnets move past each other while the train is running and generate the repulsive force. The benefits of this method are that it is incredibly stable at high speeds. Maintaining correct distance between train and guideway is not a concern (Wilson, 2021).

Wilson (2021) advised that Maglev uses an electric linear motor to achieve propulsion. A normal electric rotary motor uses magnetism to create torque and spin an axle. It has a stationary piece, the stator, which surrounds a rotating piece, the rotor. The stator is used to generate a rotating magnetic field. This field induces a rotational force on the rotor, which causes it to spin. The stator is laid flat and the rotor rests above it. Instead of a rotating magnetic field, the stator generates a field that travels down its length. Similarly, instead of a rotating force, the rotor experiences a linear force that pulls it down the stator. Thus, an electric linear motor directly produces motion in a straight line.

To summarize, the advantages of using Maglev technology might include (Wilson, 2021):

- Reduced train dwell and headway.
- High capacity to move travellers in short time.
- High density of trains sharing the same infrastructure.
- Assumed can cope with higher travelling capacities than a standard metro system.
- Longevity, there is no need to replace arils at certain period, lifespan of infrastructure is longer than conventional metro systems.
- Safety operation, maglev trains are almost impossible to derail, there is a small likelihood of impact with objects falling on the track.
- Energy efficiency, there is no friction in the system, which led to low energy consumption. Energy consumption is a major factor on operation of the metro line, Maglev system have electrical performances above standard systems.
- Low environmental impact and noise pollution.

4.7 Further Studies and Revision of Makkah Traffic Management Plan

To increase station capabilities to handle a higher number of travellers in short time, it is envisaged to develop some remodeling works, such as upgrades from 2 to 3 station platforms, with 2 platforms lateral and a central island. Such modifications may require: re-sitting of the track, building access infrastructure to station platforms (over or under ground), alteration of access to track, increase of unpaid (before ticket barriers area), upgrades of ticket barriers, commercial offices, etc.

Another solution sought is to revise Operation Plan, by introducing a system with two types of running trains: slow and fast. That will also might require station layout alteration at specific locations, respectively having two central lines for direct traffic, and two lateral line fitted with two platform each, to enable trains passing nearby.

Crowd Management System / Plan might be revised, too, to address technology upgrade and station layouts remodeling. Segregating the traffic, with this potential arrangement, Fast and Slow Lines, would determine a higher density of trains, and increase of traffic capacities. Various route scenarios should be integrated and tested with proven software, verified for design and check of traffic capacities. The anticipated impact of traffic remodeling might be in station remodeling and architecture.

5 Conclusion

Among with the technical failures of the MMMSL metro line, which conducted to the incident occurred in 2015, some incorrect interpretation of technical requirements are conducted as follows: First, the metro capacities can cope with maximum 60,000 pphpd, however it is suspected a metro system may operate in heavily congested area by maximum 45,000 pphpd. Anyhow, within the given condition, and planned traffic capacities, it suspected this line cannot operate 72,000 pphpd. Second, over 45,000 pphpd the systems based on interaction rail – wheel might not operate well. So, perhaps, superior technologies that offer superior travelling characteristics such Maglev might be the recommended ones. Third, scheme development was inconsistent with the project needs. There was no compliance to PMIF described above, either British or French or US systems. Fourth, station architectural types may not offer sufficient and fast capacity for loading and off-loading the trains. Perhaps a system with three station platforms, separated for loading and off-loading, or to be used in common for such operation may suit. Access to station platforms might not be appropriate. Fifth, the technical characteristics of some sub-systems improper selected. It is suspectable that PSD system is not performing well, due to several conditions, which include coping with travelling capacities or adaptability to local environment in Makkah. Sixth, there are some comments on the open space that a 4-line system is to be built. However, some provisions should be made in station design, and viaducts in order to plan for such upgrade, which are not visible on the constructed system. Seventh, the operation Plan of the line might not be the best selection. The software models were used, and on which high density urban system were tested. Finally, the line operation with heavy trains i.e. 12-car formation, 3000 passengers impacts on headway. A modern system operates on 90sec headway, while MMMSL achieves 240 sec. A superior technology combined with shorter trains might improve system operation and further reduce headways, even lower than 90 sec.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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