Application of System Engineering in APM Project

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***Abstract*—The construction of a new type urban rail transit is a systematic project. This paper first introduces the related theories of System Engineering and Integration. As the interface issues are complex, it is necessary to analyze the project from a system perspective. In the implementation of Shanghai Pujiang APM core electromechanical equipment system project, the system integration methods are used to instruct the system engineering process during the whole project life cycle. At the same time, this paper introduces the application of several management tools and methods to realize the scientific management of engineering technology. Through a comprehensive technical route and management approach, the integration model of the APM core electromechanical equipment system is established, and the idea of project implementation is clarified. It effectively improved the project's quality to better meet the customer's requirements.**

***Index Terms*—automated people mover, Pujiang line, system engineering, technical characteristics, system integration**

I. Introduction

The concept and application of systems engineering originated in the United States to develop atomic bomb Manhattan program. In China, system engineering applied in aerospace, the Three Gorges Project and high-speed railway projects to plan, design, manufacture, test, and achieved successful applications.

The history of automated people movers is a fascinating story of innovation by governments, companies, entrepreneurs, transportation interest groups, researchers, and individuals [1]. The construction of urban rail transit is a large-scale systematic project with huge investment, high engineering difficulty, tight construction time limit, complex technology, many interfaces and coordination work. It also involves multiple disciplines such as Urban Planning, Transportation, Civil Engineering, Power, Control, Ventilation, Reliability etc. The new urban rail transit system is highly integrated with advanced technology. Many core components need importing from abroad and the interface is complex. Therefore, it is necessary to analyze the project from a system perspective and carry out technical management and system integration.

System Engineering is both a discipline and a method, and can be understood as an interdisciplinary approach and process for implementing a system. System integration means that using a scientific approach, considering two or more interconnected systems as a whole and ensuring that the interfaces between them are logical and workable, so that the integrated system achieves the intended purpose.

Focusing on the Shanghai Pujiang Line APM project, we can figure out the integration scope and content by analyzing the technical characteristics of the APM system. Applying the method of system engineering, the process of APM core electromechanical equipment system integration can be summarized as follows: Requirements Definition, Design, Product Realization, Product Verification and Validation, Product Delivery.

Through the whole life cycle concept, we can establish the technical route of the project, and in the technical route, we use scientific project management tools to achieve the project goals. With the planning management, we can develop the project technical route. With the interface management, each participant and each subsystem engineers are linked together, and the various distinguished subsystems are closely linked. With the configuration management, we can make sure all engineers are on the same baseline. Through scientific evaluation and using decision-making tools, we decide the technical process carrying out step by step.

II. System Engineering and Integration

The well-known International Systems Engineering Council defines Systems Engineering as an

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interdisciplinary approach and means to enable the realization of successful systems [2]. That is, system engineering is an interdisciplinary method and means of achieving system success.

The System here can be a project, such as a rail transit project, or a product. The Methods here include technique routes and project management. The Process here includes a full life cycle of design, manufacturing, commissioning, operation and maintenance.

The theory of Integration is not only a system of overall control, but also the process of project implementation. System integration covers the range of technologies, engineering and management. The various elements and resources within the system are extensively linked together to forming a multi-level structure. The multi-level structure is decomposed and implemented to ensure the realization of system objectives.

System integration is the core content of the execution of a large complex system engineering project. It is the direct embodiment of the application of System Engineering and the core content of the project execution.

III. APM Technical Characteristics

According to the American Society of Civil Engineers definition, APM is 'A guided transit mode with fully automated operation, featuring vehicles that operate on guideways with exclusive right-of-way' [3].

Internationally, for such low or medium transportation capacity, highly integrated, fully automatic operation, rubber tire walking transportation system, different countries or vehicle manufacturers naming differently, such as AGT, NTS, VAL [4]. APM comes from the transportation between the terminals in the airport. As the technology developing, it is gradually applied in the city commuting traffic area with its flexible alignment, low noise, automatic driving, and the modern design. Compared with the urban railtransit metro system, APM mainly differs in the way of running and guiding, alignment restriction, driving modes, trainset formation, power supply and etc.

A. Running Way

The APM uses automotive rubber tires bearing load and walking on the concrete or steel surface. By using of rubber tires, it can effectively reduce the running noise, especially during the small radius curve, avoiding the howling of steel rail system. According to the relevant test data, compared with steel train, rubber tire noise can be reduced by 3 to 8 dB.

B. Guideway

APM vehicles have special steering wheels on both sides of the car or in the center bottom. The guide wheels are guided by the guide beam. Guidance can be divided into two categories: side-guide or center-guide. The center-guide APM is represented by Bombardier INNOVIA300, while the side-guide APM is represented by Mitsubishi Crystal Mover and Siemens VAL208.

C. Alignment and Profile

The APM Tire-pavement adhesion capability is greatly improved compared to the metro Steel Wheel-rail, so it is easy for the vehicle to climb up and down. The civil works can easily pass through the difficult areas in the city. APM vehicles using a single-axle bogie, the vehicle length and the distance between two bogies is short, all these contribute to passing through a smaller radius curve. It contributes to realize the design simplicity, time-savings, lowest costs, aesthetics and the high quality required [5]. Flexible alignment and profile can reduce the conflict between the newly construction and the existing structures in the city, reduce the demolition and relocation, and reduce the construction cost.

D. Driving Mode

APM is highly integrated with advanced Driverless Operation System, which can make the train unmanned and reduce station staff. In normal operating mode, the signal system automatically controls the platform doors to achieve the following integrated functions: monitoring passengers getting on and off, controlling the opening of vehicle doors and PSD, controlling the closing of vehicle doors and PSD, monitoring the horizontal gap of stations, monitoring platform door [6]. Theoretically, the minimum system interval is 60 seconds. It is important to assess how well the system meets the Operations service contract requirements by measuring the performance and availability [7].

E. Trainset

Each car of the trainset owns it's drive and control system. It can be marshaled flexibly. It is convenient and quick to connect and unlock the vehicles. The marshals can be freely combined from 1 to 6 cars to meet different levels of transportation demand.

The APM system is highly integrated with platform screen doors, the communication and signaling systems, unmanned rubber-tired vehicles, concrete or steel running pavements, dedicated power rails and guide beams, tiny switch mechanisms etc.

IV. Integration Mode and Scope

In China's high-speed railway engineering area, most of the projects use the system integration method in design, construction, operation. In the field of urban rail transit project, the work of system integration is mainly done by the authority or the agent company.

In 1962, when the airport now known as Washington Dulles International Airport opened, it featured an innovative system of mobile lounges to transfer passengers from the iconic main terminal building to aircraft waiting on the tarmac [8]. The APM advanced technology and highly integrated features determine the necessity of an experienced supplier to provide core equipment such as vehicles, signaling, switches and other key elements that are closely linked to the operational safety and efficiency of the system. The supplier is responsible for system integration, to ensure the realization of these system functions.

From the project management point of view, the use of turnkey mode can reduce the disjointedness between different departments such as design, procurement, construction. Turnkey mode contributes to realize the overall system-level optimization and maximize benefits the system. It is beneficial to reduce the total project cost, reduce the excessive conservative or repetitive design, reduce the change caused by the disconnection between the engineering design and the product design.

Most of the APM projects in the world are in EPC mode. In this model, the customer divides the project into traditional civil engineering such as the stations or terminals, tunnels, bridges, pipeline relocation, public transport facilities and APM core electromechanical equipment, commissioning a general contractor to complete the design, delivery, installation and commissioning of the core electromechanical equipment system.

V. Pujiang Line System Integration

A. Project Overview

The Downtown People Mover studies generated considerable interest in the late 1970s [9]. Shanghai Pujiang Line is a supplementary line in Shanghai's rail transit network, which is located at the end of the rail transit backbone network. From the noise, transport cost and other aspects of comprehensive comparison, the Shanghai Pujiang Line project selected APM.

Core electrical and mechanical equipment include: vehicle, signaling, track, control center, power rail, communication, integrated monitoring, platform screen door, depot equipment. The Consortium will be responsible for the design of the core electrical and mechanical equipment; responsible for coordinating manufacturing/installation quality and scheduling; coordinating non-core device interfaces; managing RAMS for the entire APM core system; conducting training for test and intermodal, operational and maintenance personnel, no-load trial operations.

B. Project Integration Contents

Under the guidance of System Engineering and according to the customer's requirements, system integration optimizes various technologies and products, combines the various separate subsystems become a complete, reliable, economical and effective system. It enables subsystems to work in coordination with each other to achieve the best overall performance. System integration reflected in the products or technology interfaces are as below:

Vehicle/signaling/PSD integration: Achieve the following integrated functions and related data transmission: passengers monitoring on and off the vehicle, allowing the opening of the door protection, control the door and platform door open, control the door and the security door closed, platform door anti-clip monitoring, confirm the operation conditions.

Vehicle power/rail integration: For the APM system, different APM systems have different power supply ways, and the vehicle collector boots are closely related to the power supply rails and should be designed as a whole.

Vehicle/runway/guideway integration: Vehicle, runway and guideway are highly correlated. Integrated design and commissioning ensures meet the operation comfort.

Integrated monitoring of integrated design: Integrated monitoring of integrated design includes the central ISCS hardware and software design, station-level ISCS hardware and software design, dispatch hall, depot control center, station control room layout, station control room integrated console, interface between the various facilities and equipment related to operation, system power supply and grounding system design.

C. Project System Integration Process in the Life Cycle

The application of systems engineering principles may be used to facilitate the management of these projects within a rigorous, coherent structure flowing from a clear understanding of the requirements through the complete lifecycle through to disposal [10].

First, identify the overall stakeholders' expectations and define the requirements into the overall functional requirements. The overall expectation of this project is to build a transportation system with mature technology, friendly environment and satisfying the requirements of reliability, maintainability, safety and easy maintenance. Secondly, carry out the system integration designing work based on the identified functions. It includes the overall architecture design, as well as the distribution of the various subsystems within the framework, the interface definition. The designing work can be divided into three stages: conceptual design, preliminary design, detail design. Next, realize the frozen design to production or construction, including individual components, products, subsystems, etc. Once the subsystem products get ready, carry out debugging to verify the design interface and product performance, verify the system requirements are all achieved. Finally, put the verified integrated system into practical operation.

D. Project System Integration Technical Management

In the system integration route, we cannot do without systematic technical management methods. The customer, airline, tenant, design consultants, construction contractor and system supplier should coordinate as one team to accomplish the project [11]. We need to integrate the technical input into a coordinated cooperation that focuses on the key objectives of the project such as performance, cost and schedule, and ensures that all functional interfaces are compatible, ensure that requirements are fed back, ensure that the design, manufacturing and integration process is traceable.

At the same time, identify engineering risks, exploring ways to mitigate them, developing risk reduction plans and reviewing them periodically to ensure risks are properly handled.

With the planning management, we can develop the project technical route. With the interface management, each participant and each subsystem engineers are linked together, and the various distinguished subsystems are

closely linked. With the configuration management, we can make sure all engineers are on the same baseline. Through scientific evaluation and using decision-making tools, we decide the technical process carrying out step by step. Technical management processes include technical planning, technical control, technical evaluation, decision analysis etc.

VI. Summary

Shanghai Pujiang APM core electromechanical equipment system integration project is the third APM system project in China and is the first turnkey project to be implemented mainly by domestic OEMs. This article establishes a comprehensive technical route and technical management approach to guide APM core mechanical and electrical equipment system integration project. It is a comprehensive and scientific technical route that ensures that the project development process is controllable, schedule is achievable, and technical data and changes are traceable.

Due to space limitations, this article does not spread out the integration of the various processes in the planning process, as well as integrated management tools. In the actual implementation of the project, the application of the Project Roadmap, Demand Management Matrix, Work Breakdown Structure and other project methods played a guiding role in the project implementation.

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