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Architecture Integration of Future ATM System based on Meta-Model

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Abstract

The new generation of the ATM (Air Traffic Management) is a typical "System of systems", which needs to adopt model-driven method of complex system engineering, and deal with a variety of flight operational requirements. Driven by architecture, it makes architectural design from top to bottom, and coordinates the relationship between ATM system architecture, airline operational control center system architecture and the airborne system architecture, achieving seamless integration with airport facilities and management and ATM center.

This paper focuses on each stage of current ATM architecture design, and propose an integrated process of the future ATM architecture design based on meta-model, and concentrates on information transmission, automatic model generation and domain knowledge accumulation in different stages of the ATM, like scenario modeling, system requirements analysis and functional architecture design. It can be used to support different application needs such as the research of ATM architecture and the systematical demonstration based on model.

Keywords: ATM, Meta-model, Architecture Integration, Architecture design

1. INTRODUCTION

The new generation of the ATM is an integrated and networked system based on new technologies, for instance, satellite navigation, data link communications, automatic monitoring, collaborative decision making and system wide information management [1]. Involving multiple operational nodes and their information interaction and collaboration, such as aircraft, airport and airlines, it is a typical “System of systems” (see Figure 1). Recently, various countries have put forward future air traffic operation development planning including Next-Gen, SESAR, CAAMS, etc., which make new requirements on the avionics system capability of the new generation of aircraft.

The requirements include avionics system needs for airport surface management application, avionics system needs facing to equivalent visual operation, the 4DT operating oriented avionics system needs, data communication capacity to support transoceanic flight and aircraft separation management, the ability to navigate for transatlantic flight, comprehensive surveillance capacity to support all-weather flights and abilities of comprehensive information service. Thus, requirements traction of the ATM architecture design puts forward higher request. Designing ATM architecture from top to bottom, coordinating the relationship between ATM system architecture, Airline operational control central system architecture and the airborne system architecture, and seamlessly integrating airport facilities and management and air traffic management center, has become a complex system engineering issue with architecture as the core [2].

During the traditional system design and development process, different groups or departments are responsible for different processes, and the requirements are written on paper and passed to each other. Errors introduced during the design process with traditional methods, are usually discovered while the final testing stage, resulting in the rewriting of relevant technical indicators, the waste of a lot of time, energy, manpower, and may even the redesign of system. In the process of

model-based design, the design results of each stage are no longer transmitted through paper documents, but through models. Within each design stage, the model can be used to verify design consistency and find errors. On the basis of SoS architecture design method, this paper focuses on each stage of current ATM architecture design, putting forward an integrated process of the future ATM architecture design based on meta-model, and concentrates on information transmission, automatic model generation and domain knowledge accumulation in different stages of the ATM, like scenario modeling, system requirements analysis and functional architecture design [3].

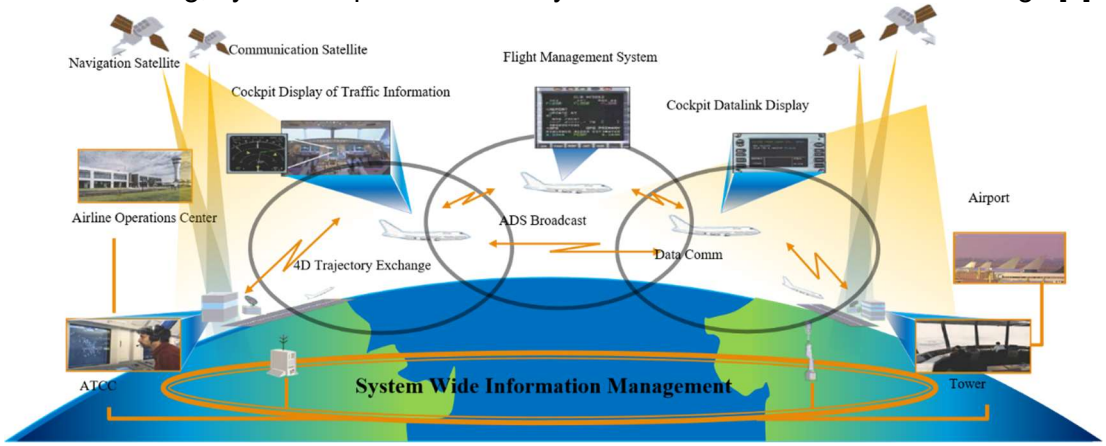

Figure 1 Air Traffic Management.

2. THE TRADITIONAL MODEL-BASED ATM ARCHITECTURE DESIGN

The model-based ATM architecture design takes the operational scenario as the input and carries out the architecture design from two dimensions of time-space domain and logical domain，referring to the SoS architecture framework. The main steps include operational scenarios modeling, operational architecture modeling and functional architecture modeling. In time-space domain, the task execution analysis is carried out based on the scenario modeling model, and expressed by the visualization chart and data; in logical domain, functional logic, timing sequence, information exchange analysis is completed, with the architectural features evaluated.

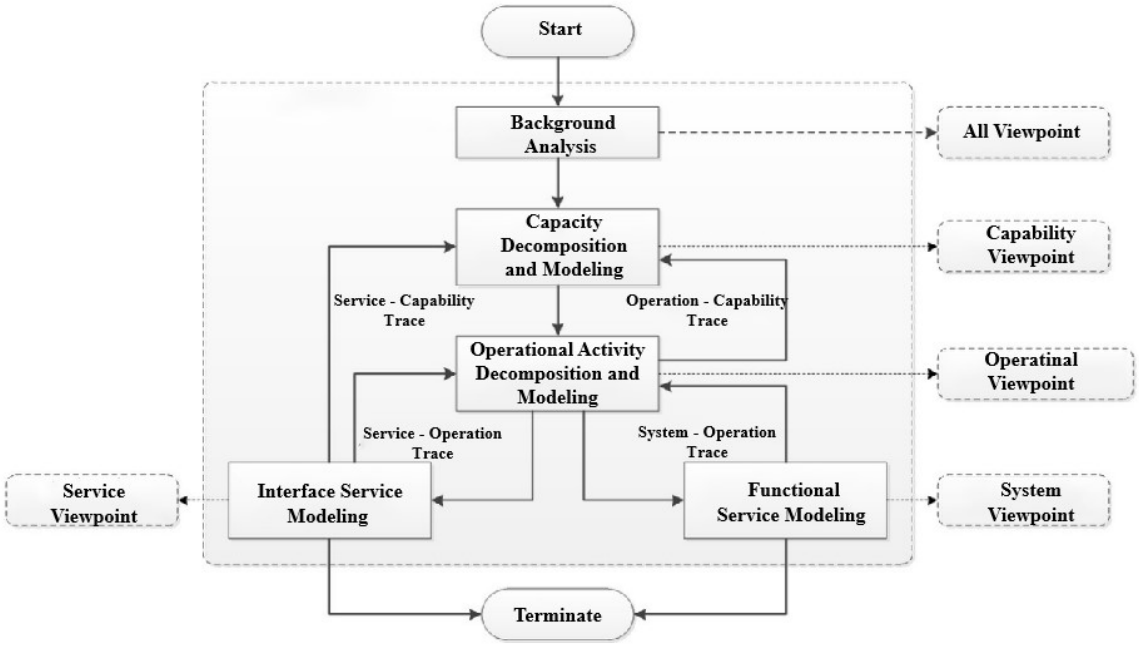

Figure 2 Design process of ATM architecture based on model.

According to the standard architecture framework, modeling and analysis of the model-based ATM architecture is under the guidance of the system development methodology. Through the modeling and simulation of the system operational and functional architecture, the key capability

requirements of the ATM are analyzed. At the same time, through the establishment of the architecture modeling and simulation integrated environment, the comprehensive integration is carried out through the system operational model and functional requirements model in the architecture design stage, so as to meet the requirements of "early synthesis and early verification" and improve the design efficiency and confidence.

Firstly, the concept of ATM top-level operation is designed, and the typical operation scenarios of the ATM are designed according to the actual situation. Build executable operation architecture model and system architecture model respectively from operation perspective and system perspective; The simulation tool is used to construct a visual typical scene of the ATM for deduction analysis, and the operation scene is co-simulated and verified with the generated model, finally forming a structured capacity demand of the ATM, which is fed back to the user for confirmation. The confirmed requirements will provide the ATM developer with guidance for further research and development of ATM and avionics system equipment.

3. NEW CONCEPT OF THE ATM ARCHITECTURE INTEGRATED DESIGN

3.1 Integrated architecture design

On the basis of the process of ATM architecture design, the meta-model based ATM architecture integrated design carries out the in-depth design and integration of each stage of the existing ATM architecture requirements analysis, by constructing the domain-oriented operational scenario, operational architecture and functional architecture of ATM. During the stages like requirements analysis, operational scenario modeling, operational architecture, functional architecture and physical architecture, design information transmission, automatic model generation, domain knowledge accumulation are focused to support users to conduct systematic demand demonstration and analysis. The architecture design is carried out with the service-oriented idea, and the system engineering methods, processes, tools and data are taken as the core to establish a service-oriented integrated design system for the operational architecture.

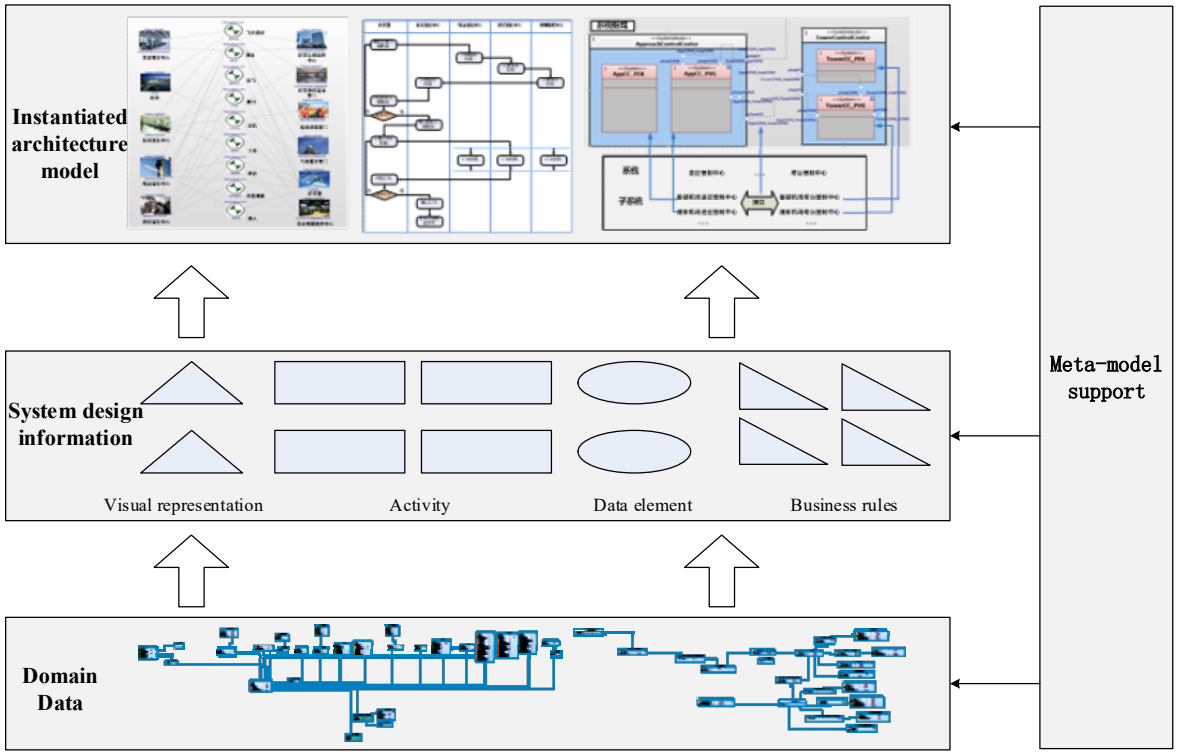

Figure 3 Integrated design concept of ATM architecture.

The ATM architecture design includes design dimension and evolution dimension. In design dimension， with the existing model-based system engineering design process, methods and tools as the core, through the development of ATM operational scenario, operational architecture, functional architecture meta-model, it builds a structured ATM domain knowledge base, and deeply combines the design-recommended technology based on knowledge map and design based on the ATM model, to improve the efficiency and quality of design while accumulating design knowledge

explicitly; In evolution dimension, ATM architecture in the whole life cycle has the characteristics of adaptive evolution. ATM architecture design based on meta-model provides the "initialization" of ATM core, with the unceasing change of operational environment, operational mode, forming knowledge expression of dispatching management and providing training data for growth of ATM architecture evolution. Then, operational ability has risen in spiral.

3.2 Technical features with model and data as core

The mode-based ATM architecture design method provides a process analysis method of ATM, and formalizes the definition and expression of each element of ATM. In this paper, the elements in the operational architecture design process of the model-based ATM are implemented in the meta-model design, and the design process and design information are expressed in a unified way. The meta-model based integrated design system of the ATM architecture is established with data as the center.

The model-based ATM architecture design includes the stages of operational scenario modeling, operational architecture, functional architecture and physical architecture, etc., with a wide span of domain hierarchy and great differences in the representation of models at different stages. The relationship between models in different modeling layers is complex, and there are overlapping and consistent parts as well as incremental or refined contents between different modeling layers. As a result, the model systems of different modeling tools cannot be fully mapped one-to-one. The higher-level modeling knowledge is more abstract and related, while the lower-level modeling knowledge is characterized by specific description, detailed data and complex knowledge traceability between layers, which makes it difficult to establish continuous design assistance from the top to the bottom.

Adopting the service-oriented idea to design the architecture, this paper takes the data as the center and establishes the integrated design system of meta-model based ATM architecture, and establishes the complete and standard design process of the ATM operational scenario-operational architecture-functional architecture-physical architecture-structural demand generation. Then, it forms a standardized design model information storage, interaction mechanism and the introduction of knowledge management technology, with tool integration, knowledge reuse, ease of use, flexible expansion and other characteristics.

3.3 Usage process of integrated design

Typical usage process of the integrated design of the architecture of ATM based on the meta-model is shown in Figure 4 as follows:

1) Assist to establish system scenario

Through Doors, system operational scenario document or system scenario data acquisition template, automatically generate system scenario, complete scenario modeling with the support of plug-ins, generate system scenario structured data and store it in the data system.

2) Assist to establish operational scenario

Automatically generate operational scenario model according to structured system scenario data and operational scenario data acquisition template, complete operational scenario editing with the support of plug-in, generate structured data of operational scenario and store it in the data system.

3) Assist to establish operational architecture

Automatically generate operational architecture models, mainly including CV and OV, based on structured system scenario data and operation architecture data collection template; complete operational architecture modeling with the support of plug-ins; generate structured data of operational architecture and store it in the data system.

4) Verification of operational architecture execution

Generate executable operational architecture model, associate it with system operational scenario, and complete execution verification of operational architecture.

5) Assist to establish capability architecture

Automatically generate capability architecture model according to structured capability architecture data and capability architecture data collection template, complete functional architecture modeling with plug-in support, generate capability architecture structured data and store it in the data system.

6) Assist to establish functional architecture

Automatically generate functional architecture models, mainly including SvcV and SV, based on

structured operational architecture data and capability architecture data collection template; complete functional architecture modeling with the support of plug-ins; generate structured data of functional architecture and store it in the data system.

7) Assist to establish physical architecture

Automatically generate physical architecture model according to structured functional architecture data and physical architecture data acquisition template, complete physical architecture modeling with the support of plug-ins, generate physical architecture structured data and store it in the data system.

8) MBSE model and structured requirements delivery

Based on the structured data of the design results of each stage, output related models for further system design and output structured requirements to Doors requirements management software.

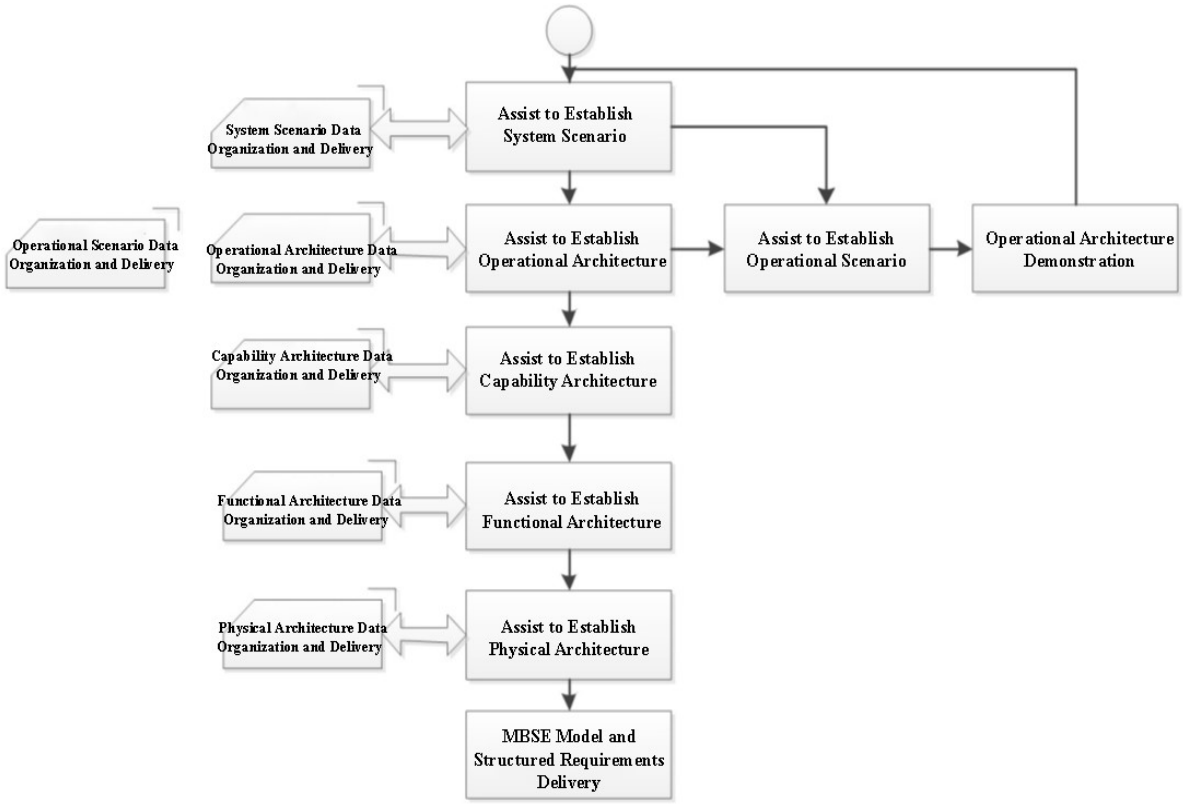

Figure 4 Typical usage process of meta-model based ATM architecture integrated design

4. KEY TECHNOLOGY

4.1 Integrated design framework of air traffic control system based on metamodel

Meta-model based ATM integrated design is on the basis of modeling analysis process of ATM architecture, and integrates the each stage of existing ATM requirements analysis deeply. By developing the operation scenario, operation architecture and functional architecture metamodel of the air traffic control system, a structured knowledge base such as architecture design domain dictionary and rules is constructed. It focuses on requirements analysis scenario modeling, operational architecture, functional architecture, physical architecture design in different stages of the information transmission, automatic model generation, domain knowledge accumulation, realizing the model library management in requirements modeling of ATM, including operational architecture model, functional architecture model and relevant test and verification model, etc., to support users in systematic requirements demonstration and analysis.

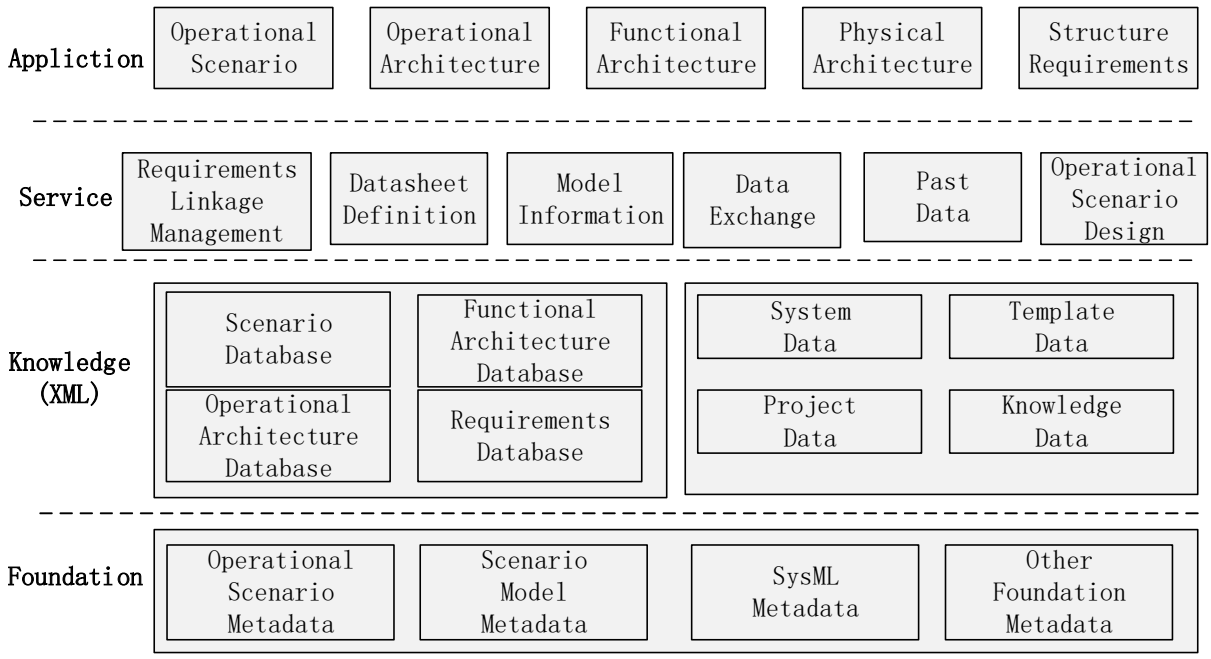

Figure 5 Integrated design system framework.

The responsibilities and connection forms of each stage are:

1) Foundation layer

The foundation layer provides the definition of operational scenario meta-model, scenario model meta-data, SysML meta-data, AADL meta-data and domain meta-data, required by the architecture design of ATM. It provides a unified standard for the expression, organization and storage of the design information of the ATM architecture.

2) Knowledge layer

The knowledge layer provides business data and management database required for the design of ATM, including the system scenario database, operational architecture database, functional architecture database, physical architecture database and management database, etc., which are implemented by the way of relational databases and files, providing data for the realization of various services in service layer.

3) Service layer

The service layer provides all kinds of functional services for the upper business, which can be divided into five forms: data template service, model information service, data exchange service, historical data service and system management service, so as to realize the separation of business and data and improve the flexibility of future system expansion.

4) Application layer

The application layer mainly provides convenient integrated plug-in for the use of various design tools in the design process of ATM architecture. Under the condition of not changing the way users use it, it provides users with graphical auxiliary function of design information, which is convenient for users to quickly obtain, share and use the existing system architecture data, and improve the efficiency of system architecture design.

The future ATM is a typical complex system, which involves the dynamic behavior and information interaction of multiple nodes under different operation scenarios, and contains professional knowledge, industry standards and operation concepts in different fields. The construction of the domain meta-model of the air traffic control system requires the extraction of relevant top-level concepts based on the documents of the industry, such as ICAO, FAA, SESAR, CAAC, etc., and the review of the various components of the ATM, such as aircraft, air traffic control departments, airports, airlines and other stakeholders. Airspace structures such as sector, route and approach point, as well as interactive information such as four-dimensional track, control instructions and weather messages, form a knowledge base such as professional terminology dictionary and air traffic control operation rules. Through syntax and semantic analysis, these components of ATC system are transformed from the description of natural language to the meta-model of ATC system based on SysML [4].

4.2 Design of domain meta-model of ATM

The meta-model is a model that describes a modeling language and usually defines the abstract syntax of the model and the relationships between model elements. The construction of the metamodel can capture the basic attributes and characteristics of the model being modeled. At the same time, the metamodel also provides an organizational basis for modeling data entities and their association relations. The construction of the metamodel can provide standard terms for the modeling design of the air traffic control system architecture, define the conceptual entities or model elements of the modeling language, and also define all the data elements designed in the modeling of the air traffic control system architecture, which provides the underlying basis for the simulation verification, consistency analysis and design information accumulation of the model.

The domain meta-model of ATM normalizes and standardizes the description of ATM architecture, and solves the problems that the standard of normalized description of ATM architecture is not unified, and the exchange of model data and reuse of models is hard to be realized. The domain meta-model of ATM architecture is defined by referring to UPDM-CMM domain meta-model exchange protocol, and the domain ontology concept of ATM [5].

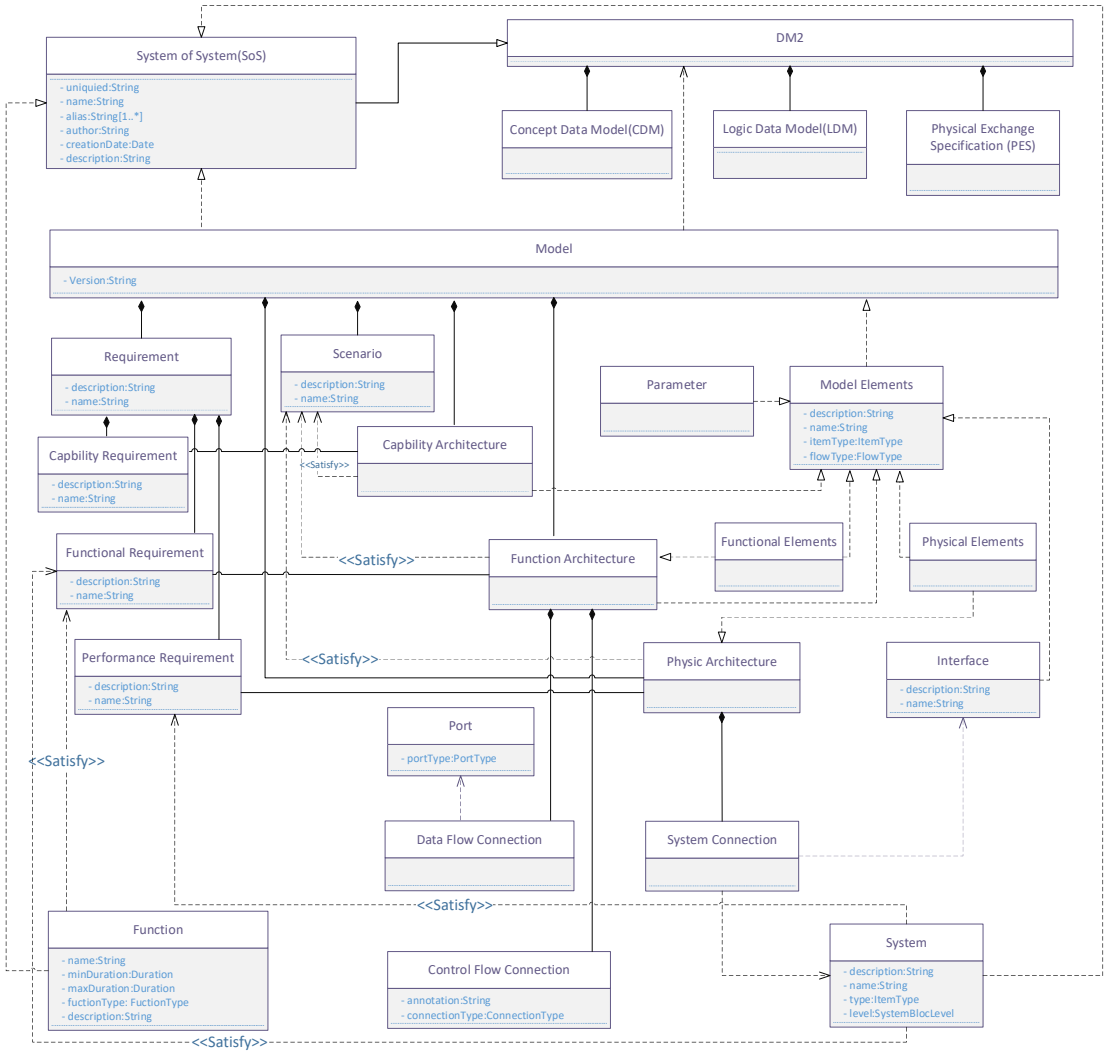

Figure 6 Design of domain meta-model of ATM.

With SysML model as the core, and be compatible with existing UPDM definition; extract ATM architecture domain core concept; cover the ATM system architecture modeling tools; specify meta-data classification; establish domain meta-data, as all kinds of reference meta-model for modeling tools to realize project data exchange, model template management and knowledge sharing. The following principles are adopted in the design and construction of the meta-model in the field of ATM. The principle of architecture-oriented design: the meta-model subject is a subset of UPDM model domain. The principle of oriented domain modeling: the domain meta-model is more specific in description and more targeted with the general UPDM data model. The principle of

service model exchange: to cover all levels and all kinds of modeling model domain as far as possible, as the model exchange middleware of each model domain. The principle of service knowledge sharing: by mapping SysML syntax, the core models of each design-related model domain are selected to merge and overlap according to the application purpose, and the domain-related models are subdivided and described to facilitate the extraction and sharing of domain knowledge [6].

4.3 Design of data organization and delivery specification

The integrates environment data of ATM architecture involves various types of relational databases, XML structured data, scenario/model files and other types of data, as well as subdivided model data. The data has many types and comes from different software systems, so integrating is hard.

In this paper, the domain meta-model of ATM is established as a form of data organization and transmission to realize that the data organization and transmission are related to the user design process and decoupled from the specific design tools. This paper orients towards ATM architecture modeling, correlates ATM system operational scenario data, operational structure data, capability structure data, functional architecture and physical architecture data, extracts various kinds of core meta-data modeling tool. Based on the domain meta-data, the meta-data mapping relationship of various modeling tools is established, the model transformation bridge of various modeling tools is established, the data transfer specification based on XML is established, and the model delivery channel of modeling tools is realized.

Operational scenario design information mainly includes operation concept, operation rules, operation environment, stakeholder nodes, operation task decomposition, operation activity analysis and other scene elements design. Operational scenario modeling can realize the visualization of the designed operational scenario, including operation environment visualization, operation task visualization and operation relationship visualization.

Structured storage and encapsulation can be realized through data-based description of the visual elements, which provides the basis for the consumption of model information. Guided by SoS architecture framework, the operational architecture and functional architecture model decomposes the operational tasks and system functions of ATM architecture design to form the system design requirements.

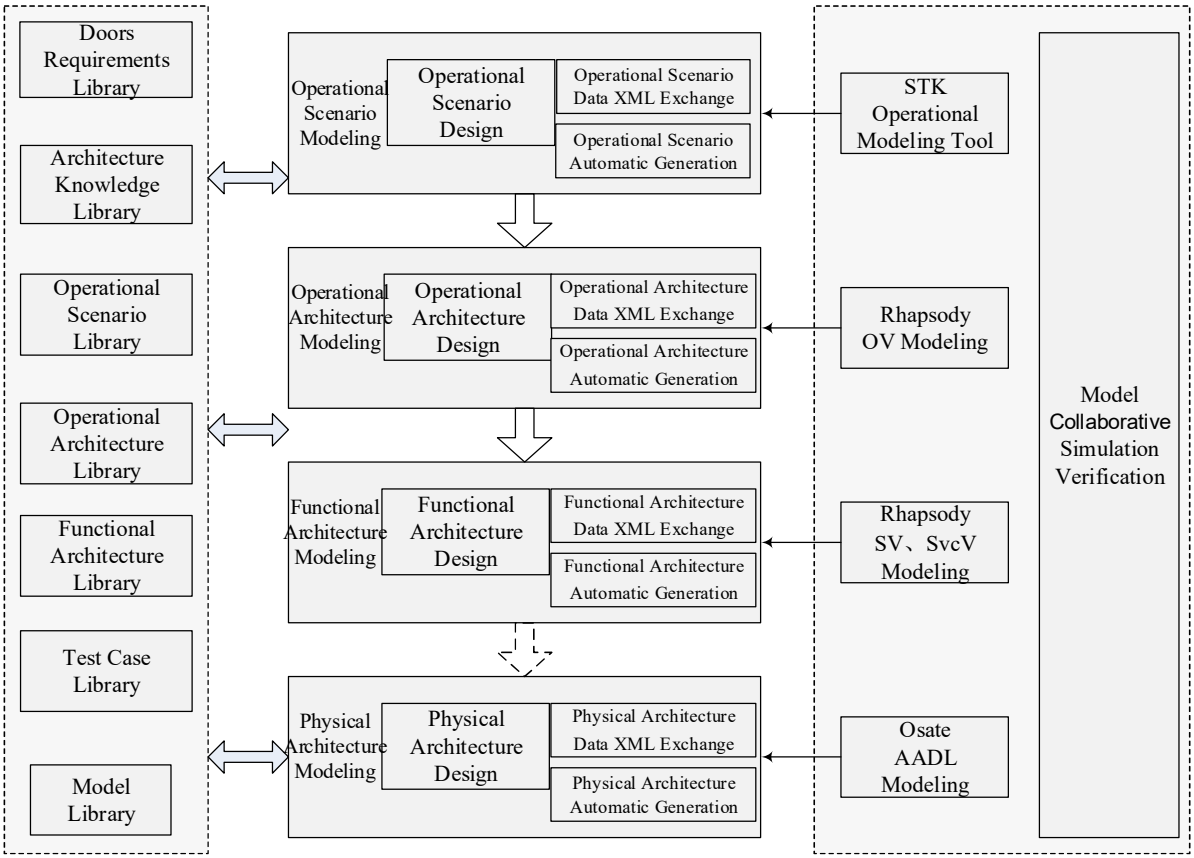

Figure 7 Data delivery based on XML model.

4.4 Multi-layers model collaborative simulation

The design process of model-based ATM architecture includes multiple stages of modeling and analysis, from operational scenarios and demand analysis to digital modeling and simulation verification of system architecture. Moreover, the analysis, simulation and verification methods of models at different layers have different characteristics, and the models developed are not the same. Therefore, the integration of architecture modeling and simulation requires that each modeling and simulation stage must have the ability of scientific and reasonable data model analysis, complete interactive information and mapping relationship matching, so as to form an integrated environment of modeling and simulation verification. Therefore, it is difficult to get through the heterogeneous modeling and analysis tools, realize the integrated simulation of tool chain, and form the seamless connection of tool chain.

The main purpose of the integrated design is to provide an integrated tool environment for the integration of systematic demonstration and architecture design, simulation and verification, and to support the fundamental research of architecture theory and model-based system of systems engineering.

5. CONCLUSION

Aiming at the design integration of all aspects of the requirements architecture design of the existing ATM, this paper puts forward the integrated design process of the future ATM architecture based on the model, focusing on the requirements analysis, operational architecture and functional architecture design of ATM. On the other hand, through each stage of design elements to carry on the design and expression in the form of meta-model, this paper provides a good way of data management, achieving the goal of formalized representation of design information. It implements the various stages of information transmission, automatic model generation, domain knowledge accumulation, and effectively support ATM architecture design research. This method has been applied in the EU-China Aviation Technology Cooperation Project carried out currently, supporting effectively the development of 4DT-based greener ATM architecture.

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7. Copyright Statement

References

[1] Qun Yi. Operation Concept of New Generation Air Traffic Management System in the United States [J]. Civil Aviation of China, 2007(8):27-31.

[2] Ding Ding. Application of Model-based Systems Engineering in Civil Aircraft Field [J]. Journal of Shenyang Aerospace University, 2012, 29(4):47-50.

[3] Acheson P, C Dagli, Kilicay-Ergin N . Model Based Systems Engineering for System of Systems Using Agent-Based Modeling [J]. Procedia Computer Science, 2013, 16(1):11-19.

[4] Kundler J . Multidimensional Meta-Modelling for Air Traffic Management Service Processes[J]. Computer Modelling & New Technologies, 2010.

[5] Zhihuai Li, Xiansi Tan, Hong Wang, et al. A method of architecture data conformance verification based on DM2[J]. System Engineering and Electronics, 201335(2):357-361.

[6] UML 2.0 Superstructure Specification[S]. OMG Document:ptc 03-08-02.