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Lead partner: Hu Haoliang (CARERI)

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E-mail:	Michael.Finke@dlr.de
Project website address:	www.project-great.eu

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	NAME	ORGANISATION	DATE
COORDINATOR	Michael Finke	DLR	30/6/2021
WP LEADER	Hu Haoliang	CARERI	11/06/2021
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EXECUTIVE SUMMARY

Addressing environmental challenges, especially global warming, is more than ever an issue for the community. This matter is becoming an increasing priority at regional and global level. Commitments have been made to reduce the aviation's environmental footprint. Global air traffic is contributing to climate change, affecting local air quality and, consequently, affecting the health and quality of life of all citizens. The air traffic is growing and expected to continue growing significantly in the future to cope with the increasing demand for mobility and connectivity. A long-term effect on the environment from aviation sector, mainly caused by aircraft noise and exhaust gases (especially CO_2, nitrogen oxides NO_x and methane), make it a clear target for mitigation efforts. The future growth of aviation shall go hand in hand with environment sustainability policies. Therefore, studies and research are being conducted worldwide exploring possible optimization of the aircraft technologies as well as Air Traffic Management (ATM) operations. Given the close interdependency between several flight parameters, including the route of flight, and environmental impact, optimization in flight trajectory design and air traffic control (ATC) operations are an appropriate means to reduce the emissions in short- and medium-term time frames.

The international project "Greener Air Traffic Operations" (GreAT) has been launched in line with this objective. This Horizon 2020 project is conducted in cooperation between 6 Chinese and 7 European partners.

Through the efforts made in the previous work package (WP2.1) of GreAT project, a detailed analysis and comparison of ATM operational baseline in Europe and China has been performed, and some key concept elements have been derived to describe a 'greener ATM concept' [Finke 2021]. However, as greener ATM system is a complex system, a system architecture is needed to define how the involved components fit together and allow for modeling and reasoning about possible evolution of the system [NASEM 2015].

This document aims to create such architectures both from the view of air traffic operation and ATM system following commonly-used MODEL-BASED SYSTEM ENGINEERING (MBSE) methodology and an architecture description framework which provides the architecture modeling principles.

First the requirement analysis is performed from the top-level operational concept of TBO, to analyze and establish a set of gate-to-gate air traffic management operation processes supporting TBO, and to provide detailed descriptions of the ATM operation activities involved in each operation phase.

Then the MBSE-based greener ATM architecture development process is illustrated followed by the detailed introduction of used architecture description framework and architecture development method.

Finally, according to this process, the detailed design of operational architecture is conducted. Different models are built from operational and system view respectively, each model describes some specific elements of the greener ATM system. These models together establish the operational architecture and system architecture of greener ATM system.

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GLOSSARY

Acronym	Signification
4DT	4-Dimensional Trajectory
ACACIA	Advancing the Science for Aviation and ClimAte
ACC	Area Control Center
ADS-B	Automatic Dependent Surveillance-Broadcast
ADS-C	Automatic Dependent Surveillance-Contract
AGL	Above Ground Level
AIM	Aviation Information Management department
ALTERNATE	Assessment on Alternative Aviation Fuels Development
ANS	Air Navigation Services
ANSP	Air Navigation Service Provider
AO	Aircraft Operator
AOC	Airline Operation Centers
APP	Approach Control Center
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control, Air traffic Control
ATCO	Air Traffic Control Operator
ATFM	Air traffic Flow Management
ATFMC	Air Traffic Flow Management Center
ATOT	Actual Take Off Time
ATM	Air Traffic Management
AU	Airspace User
CAAC	Civil Aviation Administration of China
CAAC-ATMB	The Air Traffic Management Bureau of Civil Aviation Administration of China
CAAMS	Civil Aviation ATM Modernization Strategy

CLIMOP	CLimate assessment of Innovative Mitigation strategies towards OPerational improvements in aviation
CTA	Calculated Time of Arrival
ELDT	Estimated Landing Time
EPP	Extended Projected Profile
ETA	Estimated Time of Arrival
MBSE	Model-Based System Engineering
NOTAM	Notice(s) to Airmen
OMEs	Original Equipment Manufacturers
OV	Operational View
SoS	System of Systems
SV	System View
SysML	Systems Modeling Language
TBO	Trajectory-Based Operations
TOBT	Target Off-block Time
UML	Unified Modeling Language

1. INTRODUCTION

1.1. PURPOSE OF THE DOCUMENT

In WP2.1, the concepts of future greener 4DT-based air traffic operation in China and Europe have been proposed and analyzed [Finke 2021]. However, these operational concepts just serve as the high-level ideas about future air traffic operation that meet the requirements of a sustainable aviation development. They need to be gradually improved via continuous iterations for specific use cases / operational scenarios, and implemented via the design and development of related supporting systems, that cover aircraft and its airborne systems (mainly avionics systems), ATM automation systems, information management systems, etc. With the upgrade of such systems, flight procedures and related standards and specifications should consequently evolve, be improved, and adjusted for consistency with the new operational concepts. Architecture can act as a bridge connecting the definition and implementation phases of operational concepts. It provides a structured description of the air traffic operation system that follows the greener concept. From the operational perspective, the architecture identifies the operational activities of each flight phase, the involved operational nodes, and the information exchanges among these nodes, and clarifies the responsibilities and needs of all stakeholders. From the system perspective, it defines the composition of the system, captures the functional requirements of the systems and subsystems, supporting system development process. The purpose of this document is to describe the greener ATM architecture, which makes the link between operational concepts in WP2.1 and later technology research and systems development in MWP3, MWP4, MWP5, and supports the validation activities in MWP6 and MWP7.

This document has been created by CARERI with support from CIRA who prepared a transitional report about the greener TBO-based ATM process analysis from European operation point of view [CIRA 2020]. These reports served as an input and reference for the modeling of operational architecture, by providing identification and description of different flight phases and the flight processes & sub-processes for each flight phase.

As this document is mainly contributed by Chinese partners, some of the ATM terms appear in Chinese terminology in the whole document. The equivalent in European terminology can be found in D2.1.

1.2. SCOPE

The 4DT-based ATM system is a typical complex system with the following characteristics [Jamshidi 2008]:

1) a multi-business, multi-agent system involving the cooperation and information exchanges of multiple subsystems such as aircraft, satellites, and various stakeholders on the ground,
2) each subsystem can play its own role and operate independently of other systems;
3) a dynamic system, involving many evolutionary and emergent behaviors;
4) there is a central radiated or distributed network topology among the nodes that defines the connections between them;
5) effective study of the ATM system requires comprehensive knowledge across various research areas, including engineering, economics, policy, and operations.

In summary, the analysis of ATM system requires an SoS (System of Systems) engineering approach.

In this document, the modeling process of green air traffic operation system architecture will be described using a MODEL-BASED SYSTEM ENGINEERING (MBSE) architecture development methodology. First, a 4DT-based flight process is described as a typical operation scenario in which the activities of stakeholders and the information exchanges in each flight phase are identified. Then, the framework and methodology of architecture development are introduced as well as the steps needed for the architecture models building. The detailed modelling process will follow, including the modelling of high-level operational concept diagrams, sequence diagrams and state-machine diagrams from both operational and system views, which clarify the requirements of the ATM system supporting the green operational concept. Finally, the whole architecture development is concluded to illustrate the benefits of using MBSE approach and to give an initial outlook of the research on architecture validation in the following work package.

1.3. INTENDED READERSHIP

This section describes the intended audience for this document. In general, readers of this document can be:

1) Readers internal to the project, using this document as input for their own activities.
2) Readers from the GreAT sister projects (ACACIA, CLIMOP and ALTERNATE), to follow latest developments and approaches, and to drive scientific exchange between the sister projects. This is for the purpose of aligning the activities of all four projects and to identify synergy effects. Finally, this document can also serve as reference for scientific publications.
3) Readers from the GreAT Advisory board, to provide input and to follow the developments from a stakeholder point of view.
4) Readers involved in current and future projects dealing with reducing the impact of aviation on climate change, especially to build upon the approaches described in this document; and to align other developments (e.g., modifications to aircraft propulsion and airframe) with it.
5) Readers from air navigation service providers (ANSPs) or other stakeholders not involved in the project but effected from its improvements (especially airports, airlines, and air traffic control (ATC) equipment providers).
6) Standardization bodies and regulating authorities / organizations, such as ICAO, European Union Aviation Safety Agency (EASA), EUROCONTROL or Civil Aviation Administration of China (CAAC).
7) All other interested members of aviation community.

1.4. STRUCTURE OF THE DOCUMENT

This document contains the following sections:

Chapter 1 Introduction – Describes the purpose and scope of the document, the intended audience, and the document structure.

Chapter 2 Requirement Analysis – Describes the top-level requirements from the perspective of global ATM development strategy, and provides simple analysis of activities and information exchanges of stakeholders for each flight phase.

Chapter 3 Overall Design of Architecture – Describes the framework and methodology of ATM architecture development based on MBSE. The object-oriented modeling approach and UML language are introduced. The overall architecture development process and modeling steps are demonstrated.

Chapter 4 Detailed Design of Architecture – Describes the detailed development process for operational architecture and system architecture. The description and UML diagram for each model are demonstrated.

Chapter 5 Conclusion and Outlook – Concludes the greener ATM architecture development process with analysis of benefits using MBSE approach and a simple outlook of the research on architecture validation in WP2.3.

Chapter 6 References – Contains the references.

2. REQUIREMENT ANALYSIS

2.1. OUTLINE OF OPERATIONAL REQUIREMENT

The trajectory-based operations (TBO) concept is a set of system-level solutions proposed by the international civil aviation community in recent years, aiming to improve ATM system security, enhance operation and fuel efficiency, reduce emissions and cope with the continuous growth of global air traffic.

The TBO operational concept was first derived from the Global ConOps released by ICAO in 2005 (Doc 9854) [ICAO 2005]. It was further clarified in NextGen and SESAR and became one of the core operational concepts of the two major programs in the US and Europe. In general, TBO is based on the four-dimensional trajectory (4DT) of the whole life cycle of flight, dynamically sharing and maintaining in real time the trajectory information among ATC, airlines, airports, aircraft, and other related stakeholders, and realizing the collaborative decision-making. The 4DT is a flight path connected by a series of points, each of which has a certain accuracy requirement in four dimensions (space and time), and thus describes the flight operation process controllable and accessible.

Currently, ICAO's TBO operational concept is still being updated and improved, and the industry has a certain degree of consensus on the connotation, structure, and significance of the TBO concept, but it is still in the early stage of exploration in terms of promoting operational mechanism development, improving system-based operation efficiency, and constructing application-oriented system, etc. The realization and application of TBO is a complex system engineering covering a wide range of areas, with a long implementation period and strong technical integration. It is important to start from the top-level operational concept of TBO, to analyze and establish a set of air traffic management operation processes supporting TBO, and to provide detailed descriptions of the ATM operation activities involved in each operation phase, aiming to promote consistent knowledge, and understanding of the operational concept and provide reference for the construction and development of future ATM systems.

2.2. PROCESS ANALYSIS

In the whole operation process, the flight is generally divided into nine phases: flight planning, taxi-out, departure, climbing, cruise, descent, approach, landing and taxi-in. Each phase involves activities and information exchanges among the aircraft and other operational nodes such as ground control centers, airports, airlines, and other aircraft.

Each of these phases is described in the following chapters. The described process corresponds to the Chinese operation procedure.

2.2.1. FLIGHT PLANNING

In this phase, the pre-takeoff flight preparation is conducted. The airline applies and obtains the approval of the route it intends to fly. The air traffic control center issues the airspace status and usage restrictions to the airline. The airline submits the intended flight trajectory, which is then delivered to the national Air Traffic Flow Management Center (ATFMC) for trajectory evaluation and confirmation. ATFMC formulates the flow management strategies and issues them to the airline, which evaluates their impact. ATFMC publishes/updates the planned trajectory to the aviation information management department (AIM), airlines, Air Route Traffic Control Center (ARTCC) and tower control center. The tower control center publishes weather information to AIM and sends NOTAMS to ARTCC. The airline submits Target Off-block Time (TOBT) to the tower control center, which assigns flight departure and taxi route and uploads the route information to the aircraft. The aircraft performs departure trajectory calculation and sends it to ATM systems. The tower control center negotiates the departure trajectory with ATFMC, airport, area control center (ACC) and approach control center (APP), which make evaluation and send feedback. The tower control center uploads updated departure trajectory to aircraft for confirmation and update. The tower control center shares the departure trajectory to ATFMC, airport, area control center and approach control center for confirmation and storage.

2.2.2. TAXI-OUT

The taxi-out phase is the phase of the flight from Off-Block until Take-Off, that includes the Surface Movement associated to the departure of a flight[1]. The aircraft arrives at the runway entrance and waits for the tower control center to issue take-off clearance. When receiving it, the aircraft confirms the takeoff clearance, enters the runway, and begins to take off according to the actual take-off time (ATOT) issued by the tower control center. The tower control center then hands over its control to the approach control center, which confirms the handover with the aircraft. The aircraft joins the departure flight flow and begins climbing.

2.2.3. DEPARTURE AND CLIMBING

The approach control center continuously monitors the departure of the aircraft. When a conflict is detected, the aircraft will inform the approach control center of the climbing conflict alert and wait for a resolution instruction and execute the instruction. The approach control center updates the reference trajectory and sends the updated trajectory to the area control center and ATFMC, which will evaluate and update the trajectory. When the aircraft is close to the cruising altitude, the approach control center hands over the control to the area control center. This handover will be confirmed by the aircraft before it reaches the cruising altitude and enters the cruising phase.

2.2.4. CRUISE

When an aircraft intends to move to a more fuel-efficient flight level, the aircraft requests a flight level change to the area control center. After the area control center conducts airspace operation situation analysis and judges that it is possible, it issues the clearance to the aircraft, which executes the flight level change and transmits the latest Extended Projected Profile (EPP) data. The area control updates the reference flight trajectory and

[1] Definition extracted from the Eurocontrol ATM Lexicon Release 2016.1

issues the updated trajectory to the aircraft and ATFMC. The AIM sends meteorological information to the area control center, which in turn broadcasts it to the aircraft. When the aircraft detects that there is a meteorological conflict in the subsequent trajectory, it will generate the adjustment proposal of flight trajectory and submits it to the airline, which submits the proposal to ATFMC. After ATFMC evaluate the proposal, it releases the updated trajectory to the area control center and the airline. The updated trajectory will be uploaded to aircraft by airline after the confirmation. The aircraft will apply for a new clearance to the area control center when it receives the updated trajectory. After getting the clearance, the aircraft will recalculate the trajectory, downlink EPP data and executes the updated reference trajectory.

2.2.5. DESCENT

Aircraft in the descent enter the airspace for approach sequencing management and request meteorological and operational information from AIM, then generate approach trajectories, and downlink them to area control center as well as the downstream approach and tower control centers with Estimated Time of Arrival (ETA) window. The area control, approach control and tower control centers negotiate the Calculated Time of Arrival (CTA) with ATFMC. Then the Area control center integrates and uploads negotiated CTA to the aircraft for confirmation and update. ATFMC negotiates CTA with airport for an Estimated Landing Time (ELDT), as well as runway and apron allocation. Based on ELDT and allocated runway and apron, the ground ATM system calculates the approach taxi route and uploads it to the aircraft. When the aircraft arrives the top of descent (TOD), it gets the descent clearance issued by area control center and begins to descend. When the area control center detects that there is a descent conflict alarm, it sends a conflict resolution instruction to the aircraft and updates the descent reference trajectory. When the aircraft reaches the control handover altitude, the area control center delivers the control to the approach control center and the aircraft confirms the control handover.

2.2.6. APPROACH

The approach control center monitors the approach process. The aircraft evaluates the CTA, and if it discovers that the CTA is not available, it makes negotiation with the approach control center to change the CTA. The aircraft adjusts its speed according to the confirmed CTA, the approach control center sequences the approach flow and issues approach clearance, while maintaining the flight separation. Airport updates the apron position and share it with the tower control center, which then updates the taxi route and share it with the approach control center. The updated taxi route is uploaded to the aircraft as well as the surface condition of the runway. The aircraft executes the final approach, when the approach control center hands over control to the tower control center.

2.2.7. LANDING

The tower control center monitors the aircraft landing operation. If the runway is not available, the tower control center reassigns another runway after negotiating with the airport. The aircraft receives the updated runway information and requests landing clearance from the tower control center. After receiving and confirming the clearance, the aircraft conducts landing and arrives at the runway end.

2.2.8. TAXI-IN

The aircraft exits the runway, and the tower control center issues the taxi-in clearance. After confirming it, the aircraft enters the taxiway. The tower control center monitors taxiing operation and issues the clearance for the aircraft to enter the apron. That ends the whole flight process.

3. OVERALL DESIGN OF ARCHITECTURE

As a complex system composed of multiple businesses and agents, the design of the ATM system architecture is of great significance to the research and implementation of the system. In this document, the analysis of the architecture framework, description language, and design methods related to the architecture is conducted to realize the design of the ATM architecture. The architecture framework can be considered as the specification of the architecture narrative, which only suggests how to describe the architecture design from different viewpoints and does not regulate how to design the architecture, the latter also requires the study of the architecture design methods, description languages, and design tools. The support of Systems Modeling Language (SysML) for architecture model description is studied, with the advantage that it integrates the function-driven idea of structured analysis with the object-oriented idea of Unified Modeling Language (UML), which provides adequate support for the representation of ATM architecture models.

3.1. GREENER ATM ARCHITECTURE DEVELOPMENT TECHNOLOGY

Architecture technology is the general term for a set of theories, methods and tools that regulate, guide, and constrain the development of architecture. It is the basis for the reasonable development of architecture, which makes it a main research orientation on system architecture at present. Architecture technology can be divided into three main categories: architecture development technology, architecture verification technology, and architecture support technology. Architecture development technology is the general term for architecture development theory, methods, tools, and other related technologies. There are four main research orientations:

1) Architecture description framework: Study the description content and specification of the architecture.
2) Architecture development methods: Study the development methods of architecture, such as object-oriented methods, structured methods, activity-based modeling methods, architecture specification models, etc.
3) Architecture description language: Provide the language for system architecture description, analysis, design, and verification, such as SysML, UML, IDEF0, etc.
4) Architecture development tools: Study and develop the tools to support architecture description frameworks, languages, and development methods.

Since the traditional document-based system engineering method extract information from massive documents, there can be divergent understandings among different designers and too many iteration processes are required, which makes information difficult to track and manage. On the contrary, model-based system engineering starts from requirement analysis, realizing consistent, traceable, and verifiable system development process using continuous evolution of models instead of documents. By describing systems using object-oriented, graphic, and visualized system modeling language, the fuzziness and ambiguity led by documents can be avoided, while system functions and behaviors can be reflected clearly and precisely [Acheson 2013]. The development process of greener ATM architecture based on MBSE methods is shown in **Error! Reference source not found.**. First, the greener air traffic top-level requirements and operational requirements of stakeholders are captured from the greener ATM operational concept, and typical operational scenario is designed according to ConOps and real conditions. Operational and system architectures are built from operation and system orientation, respectively. Visual scenario demonstration is conducted using simulation tools and jointly validated with the generated models. Finally, the structural requirements of ATM system capabilities are extracted, and delivered to users for verification. The verified requirements are provided to ATM Original Equipment Manufacturers (OEMs) for future system device development.

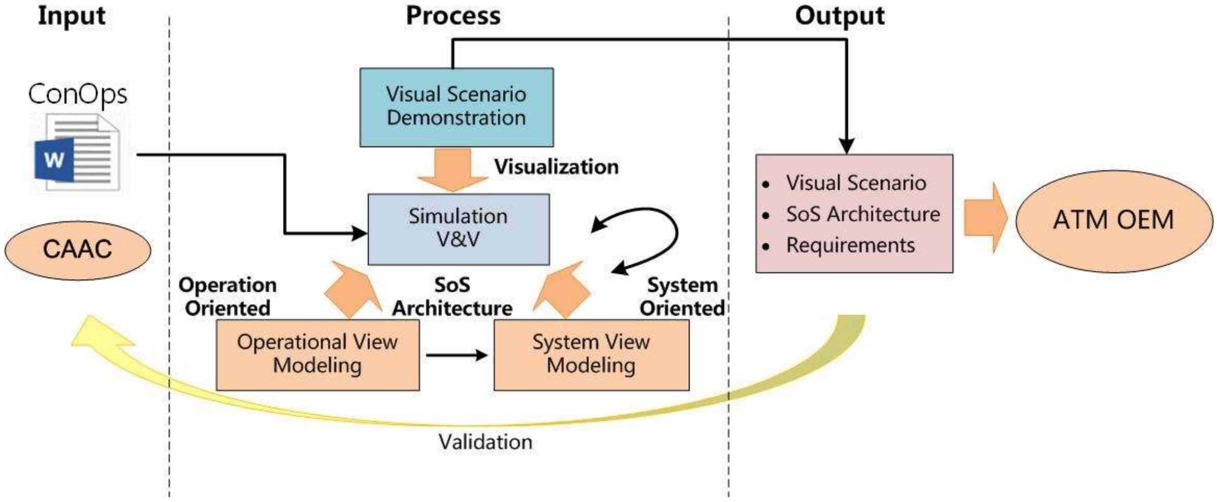

Figure 1. MBSE-based Greener ATM Architecture Development Process

3.2. ARCHITECTURE DESCRIPTION FRAMEWORK

The architecture description framework used in this document divides the architecture into an operational view (OV) and a system view (SV), which describe the architecture mainly from the two aspects: operation and system. The concepts of integrated architecture, composite architecture and joint architecture are described.

1) Operational view: OV realizes the description of operational tasks and activities, operational units and information exchanges required by the operational concept. Its main role is to determine the information requirements of the operational nodes and to describe the operational responsibilities and logical requirements. The research focuses of operational architecture includes operational concept diagrams, activity models, information exchange requirements, requirements capability matrix and basic node connectivity models.
2) System view: SV is a description of the structure of subsystems that achieve or support the operational capabilities and the interconnectivity among them. Its main role is to design the capabilities and performance of the system according to the defined criteria and requirements. The purpose is to describe the physical capabilities and characteristics that meet the operational requirements. The research focuses on system architecture and includes determining the composition of the system and the connectivity of the components, defining the constraints and behavioral boundaries of the system, defining the system interfaces, creating the interface diagrams of the system elements, and predicting the system capability to meet the operational requirements given the functional requirements and the performance parameters of the system.

Based on the two view definitions, 9 corresponding descriptive models are given, which jointly describe the construction and development of the architecture from different perspectives. These models are shown in **Error! Reference source not found.**.

Table 1. Architecture Models

View	Model Name	Description
Operational View	High Level Operational Concept Diagram	The high-level graphic and text description of operational concepts.
	Operational Node Connectivity Description	Operational nodes, connections and needlines of information exchanges among nodes.
	Operational Activity Model	Capabilities, activities, and relationship between activities, as well as input & output, executing nodes and other related information.
	Operational State Transition Description	One of the models describing operational activities, identifying the business process of responding events
	Operational Event Trace Description	One of the models describing operational activities, tracing the activities in a scenario or event sequence.
System View	System Interface Description	Describing system nodes, system composition, inter- and inner-node connectivity.
	System Functionality Description	Describing the functions executed by systems and the dataflow among systems.
	System State Transition Description	One of the models describing system functions, identifying the respond of systems to events.
	System Event Trace Description	One of the models describing system functions, refining the system-level implementation of the key event sequence in Operational View.

3.3. ARCHITECTURE DEVELOPMENT METHOD

System architecture design is a creative process that results in an implementation plan of a system architecture, which may be a building, a machine, a software system, or a product, that integrates customer requirements with the final structure. Architecture design and system product development are complementary. If product development is a forward process, then architecture design is a reverse process, which focuses on designing the structure to support system analysis. How to design the architecture and how to develop the architecture of a system according to the existing architecture framework involves the use of architecture development methods.

3.3.1. OBJECT-ORIENTED MODEL DEVELOPMENT APPROACH

Object-oriented architectures are usually Unified Modeling Language (UML) based architectures. According to a model-driven approach, the architecture is designed using UML-based models that can verify the structure and behavior of the system and generate a documented architecture. Object-oriented architecture describes the operational requirements and replaces its objects with application connotations of operational data, providing a traceable basis for the development of systems and software. Object-oriented concept is a natural partitioning of the problem space to model the problem domain in a way that is close to human thinking, and it emphasizes a direct mapping from problem domain concepts to system functions and interfaces. Object-oriented approach is based on objects, and it obtains a comprehensive understanding of the system by constructing logical models, physical models, and other related models such as static and dynamic models, emphasizing on modeling the objective world from the internal structure and building models from the perspective of behavior, which provides an orderly configuration of the components of the operation organization, as well as a method and style of design. In contrast to a structured development approach, object-oriented development approach can better maintain the original appearance of system objects, promote understanding between architecture developers and users, and facilitate the detailed design of the system, maintenance, and reuse of the architecture products. It has advantage of high degree of modularity and integration, and the development of the system is easy to maintain and extend [Hou 2015].

The object-oriented development approach is a combination of bottom-up induction and top-down decomposition. The Unified Modeling Language is a common language to support object-oriented development, which includes use case diagrams, class diagrams, sequence diagrams, state diagrams, component diagrams, etc.[Bell 2003] The main idea of the architecture development process based on UML language in existing applications is to divide the product design into three steps: Firstly, use case diagrams are used to create top-level outline descriptions, and use case models are constructed to elaborate the system usage based on the description of the operational activities and processes supported by the system, and the usage and role of the system. Secondly, use cases are used repeatedly to construct the sequence diagram of the architecture, which is a static representation of the dynamic behavior of system objects and reflects the backward and forward order of message transmission between objects. The functional decomposition of the system is obtained by expanding on the inheritance of the sequence diagram. Then, conduct the object decomposition and refine the description, the object decomposition purpose is to decompose the whole system from a single entity into several major components, so that the operational node decomposition of the system can be obtained from the operational view, and the system node decomposition can be obtained from the system structure view. With the object decomposed comes the next cycle. The decomposed object establishes correspondence with the entities in the sequence diagram, and the corresponding state transfer diagram is constructed for each object based on the object decomposition. This constructs a correspondence mapping between the UML diagram and the architecture framework model.

3.3.2. GREENER ATM ARCHITECTURE DEVELOPMENT PROCESS

In addition to the architecture development approach that can be developed and designed according to the previous subsection, the principles and technical guidance for system architecture development can also be provided based on a six-step architecture development process.

1) Determine the usage intent of the architecture. That is, to explain how the architecture meets the data requirements of each business component and the purpose of developing the architecture, and to develop a set of concise and clear evaluation criteria to measure user’s satisfaction that the architecture meets all requirements.
2) Define the scope of architecture. The breadth and depth boundaries of the architecture should be defined. This includes mission and vision, organization, systems and platforms, geographic scope, and time scale.
3) Determine the data to support the architecture development needs. Based on input from process owners, a data collection plan should be developed to select data entities, attributes, and rules for operations, systems and services, and technical standards views as needed, and to determine the scope of data requirements.

4) Collect and analyze architecture data. The data exchanged between systems, organizations, and nodes need to be correlated in the process of building the architecture, and different models, including business concept models, information flow models, organization models, and node connection models, need to be established by analyzing the data.
5) Analysis of the architecture objectives. The analysis includes: mismatch analysis between requirements and performance, business process analysis, information system processing capability and communication capability assessment analysis, interoperability assessment analysis, etc. And by iterating the architecture process (repeat step 3-5 if necessary) can better meet the designed use.
6) Build the architecture product. The final step generates a description of the architecture products based on data queries, with some adjustments and modifications if necessary. The products built by the system developers must be able to meet the requirements presented in the first step, and these products must be reusable and shareable. There are many architectural tools that support this step.

This six-step architecture development process emphasizes a data-centric approach that focuses on the data and the associations between the data. This approach ensures consistency across views, captures all essential entity associations to support many analytical tasks, and produces products that visualize potential architecture data and address communication barriers between the architecture and specific user groups or decision makers.

3.3.3. GREENER ATM OPERATIONAL ARCHITECTURE DEVELOPMENT STEPS

The Greener ATM architecture development process is SysML model-driven, architecture-centric, iterative, and incremental model development process, which integrates process-oriented and object-oriented features. In this section, the idea of combining function-driven process and object-oriented subject is used to describe the architecture from different perspectives. The architecture development is roughly sequential from the operational view to the system view.

The specific development steps for each model of the Operational View are as follows.

1) The High-Level Operational Concept Diagram decomposes the mission task into multiple key mission objectives, analyzes the various operational nodes that need to be involved and lists the operational problems to be solved.
2) The Operational Node Connectivity Description is described according to the operational nodes in High-Level Operational Concept Diagram, and the interrelationships of node operational activities, events, interfaces, and information interactions are updated from Operational Event Trace Description after Step 4.
3) The Operational Activity Model is created by refining the task objectives in High-Level Operational Concept Diagram and analyzing the operational activities and input/output information flow exchanged between them. One task objective corresponds to one Operational Activity Model.
4) The Operational Activity Model can determine the operational events of the Operational Event Trace Description diagram according to certain operational rules, and implement the event response in time sequence. One Operational Activity Model corresponds to multiple Operational Event Trace Description diagrams under certain operational rules.
5) The Operational State Transfer Description diagram combines The Operational Activity Model and Operational Event Trace Description to describe the changing process of operational activities or activity states in response to different events. Operational State Transfer Description diagram corresponds to the operational nodes in High-Level Operational Concept Diagram.
6) The System Interface Diagram decompose the operational nodes in the Operational Node Connectivity Description into multiple systems and sub-systems.

7) The System Functionality Description describes the system functions corresponding to operational activities in the Operational Activity Model. Every system or sub-system function can be traced to an operational activity it fulfills.
8) The System Event Trace Description is created by analyzing the event trace flow of operational activities in the systems and sub-systems.
9) The System State Transfer Description describes the responses of systems to the events which change their states by integrating the System Functionality Description and the System Event Trace Description.

4. DETAILED DESIGN OF OPERATIONAL ARCHITECTURE

4.1. HIGH-LEVEL OPERATIONAL CONCEPT DIAGRAM

The high-level operational concept diagram describes the system environment and the interaction between system architecture and external systems, which can be expressed in images, graphic texts, and videos, etc. This model emphasizes involved stakeholders in ATM operation and provides scenario-based operational architecture organization methods.

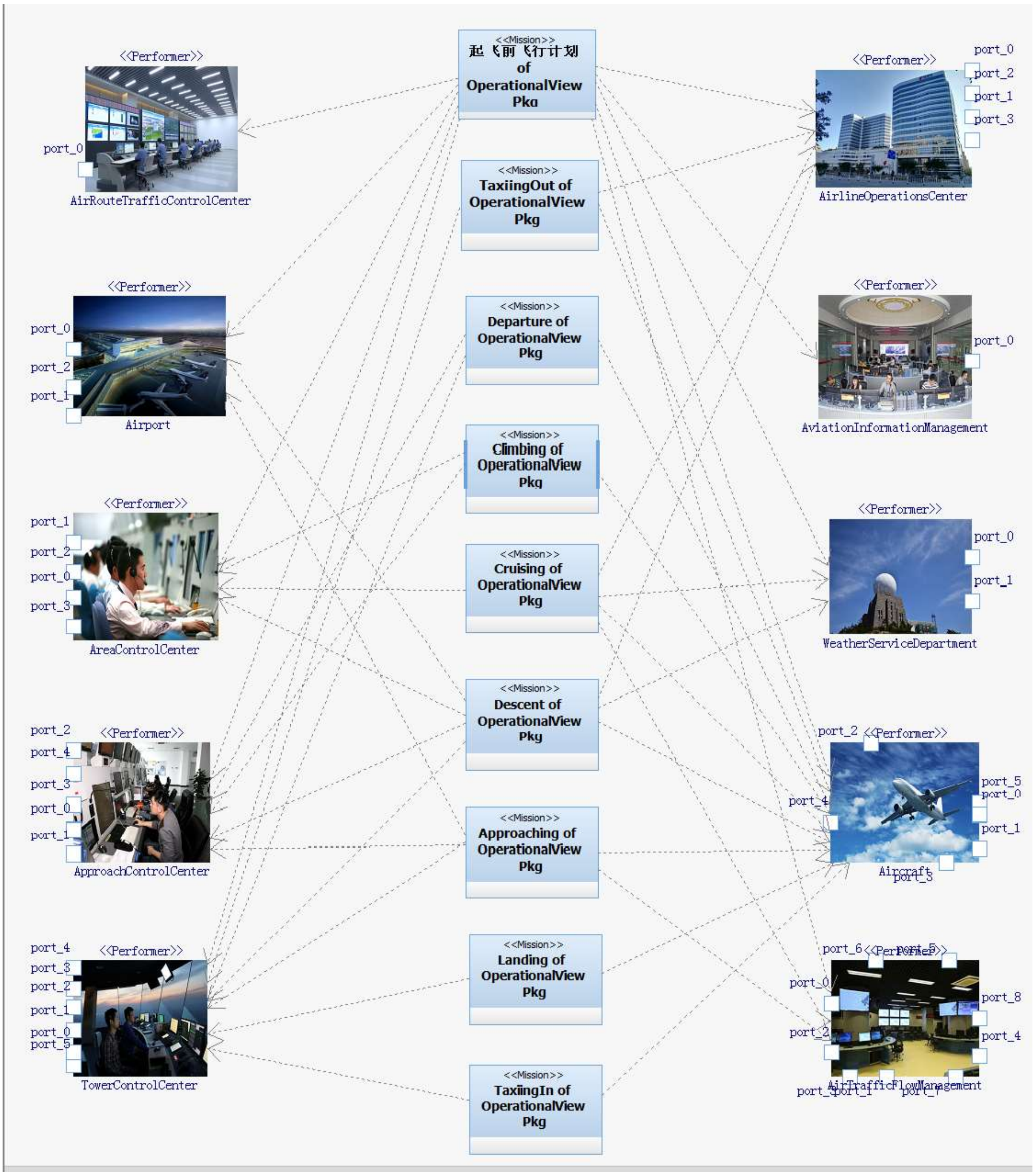

Figure 2.High-Level Operational Concept Diagram relating the nine phases of a flight to the 10 operational nodes.

The mission objective of the ATM system is to fulfill a 4DT-based greener air traffic operation process of a flight. The process includes the formally mentioned nine phases of pre-departure flight planning, taxiing out, departure, climbing, cruising, descent, approaching, landing, and taxiing in.

There are 10 operational nodes in the system: Air Traffic Flow Management, Aviation Information Management, Airline Operation Center, Aircraft, Airport, Approach Control Center, Air Route Traffic Control Center, Weather Service Department, Area Control Center and Tower Control Center.

The association lines in the diagram of Figure 2show the dependencies between the operational nodes and the mission objectives. The completion of each mission objective requires the interconnection and collaboration among operation nodes. The interrelationship between each task objective and operation nodes within the ATM system is shown in **Error! Reference source not found.**.

Table 2. Correlation between the task objective and operation nodes within the ATM system

Targeted Mission Objective	Operational Nodes involved
Flight Planning	Air Traffic Flow Management Aviation Information Management Airline Operation Center Aircraft Airport Approach Control Center Air Route Traffic Control Center Weather Service Department Area Control Center Tower Control Center
Taxiing Out	Airline Operation Center Aircraft Tower Control Center
Departure	Aircraft Approach Control Center Tower Control Center
Climbing	Aircraft Approach Control Center Area Control Center
Cruising	Air Traffic Flow Management Aviation Information Management Airline Operation Center Aircraft Area Control Center
Descent	Aviation Information Management Airline Operation Center Aircraft Airport Approach Control Center

	Area Control Center Tower Control Center
Approach	Air Traffic Flow Management Aircraft Airport Approach Control Center Area Control Center
Landing	Aircraft Tower Control Center
Taxiing In	Aircraft Tower Control Center

4.2. OPERATIONAL NODE CONNECTIVITY DESCRIPTION

Operational node connectivity description is used to describe the required nodes in terms of the mission objectives. Operational node connectivity description can be divided into two types: data-flow-oriented, which mainly describes the connections and information exchanges among the operational nodes; service-oriented, which is mainly used to describe the operational activities implemented by the operational nodes, and corresponds to the system functions. Data-flow-oriented Operational node connectivity description includes the connections and information flow, mapping events and operations in Operational Event Trace Description, i.e., operations and attributes within the node. As shown in Figure 3, the port indicates the input/output interface of the nodes, through which the 10 operational nodes can interact with each other.

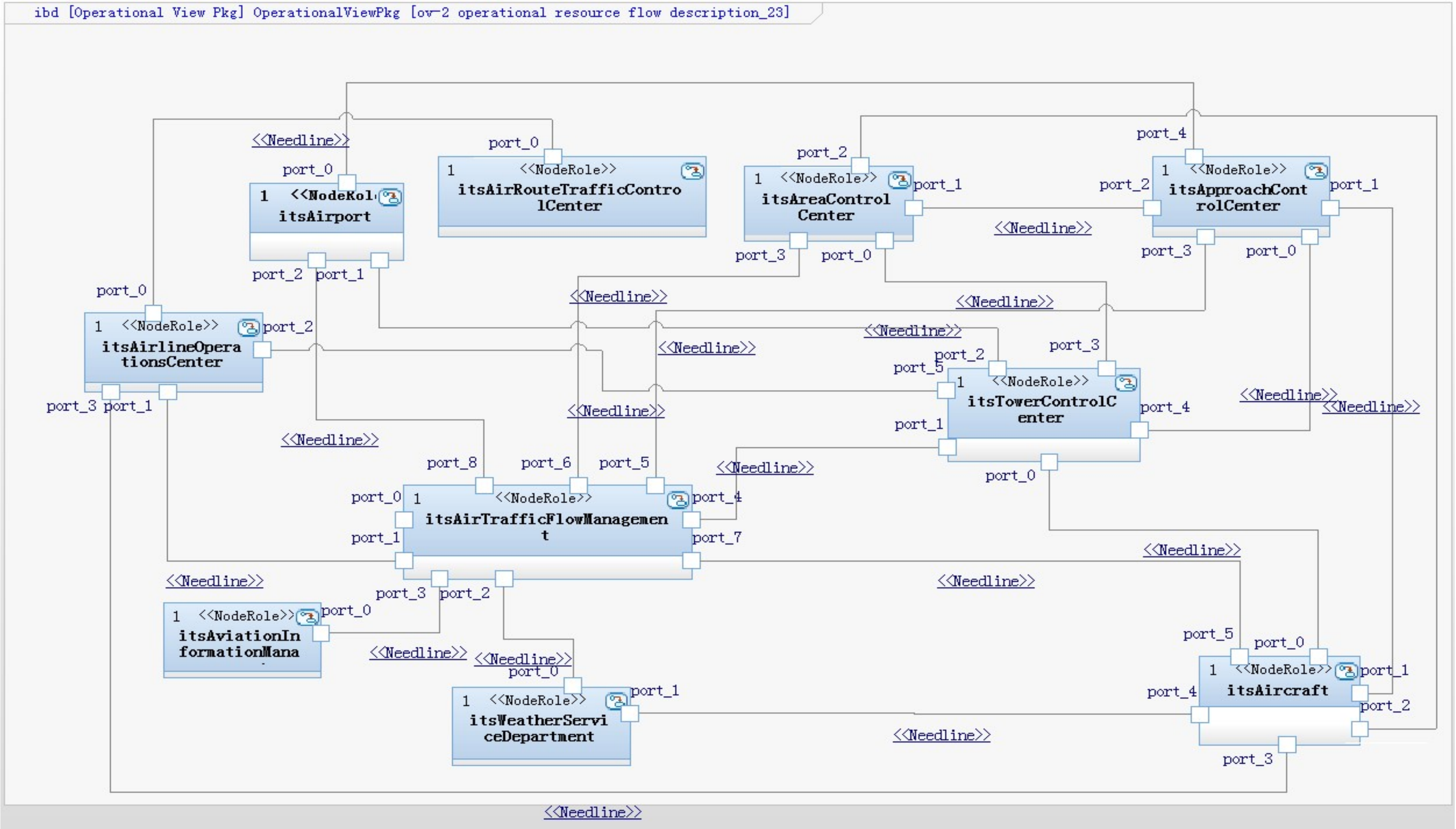

Figure 3.Operational Node Connectivity Descriptio

4.3. OPERATIONAL ACTIVITY MODEL

Operational activity model mainly describes a series of activities required to accomplish the operation objectives, which consist of activity name, input/output data flow between activities and information exchange with external environment. Each objective relates to its operational activity model, defining roles and responsibilities of stakeholders in the operation. The nodes are described in each mission objective operation event according to the nine flight phases in chronological order to achieve the mission objectives. Among them, the activity model of each flight phase also contains sub-diagrams, which can further refine the dynamic behavior of the nodes. Figure 4shows the mission management activity diagram, which just represents a top-level activity diagram.

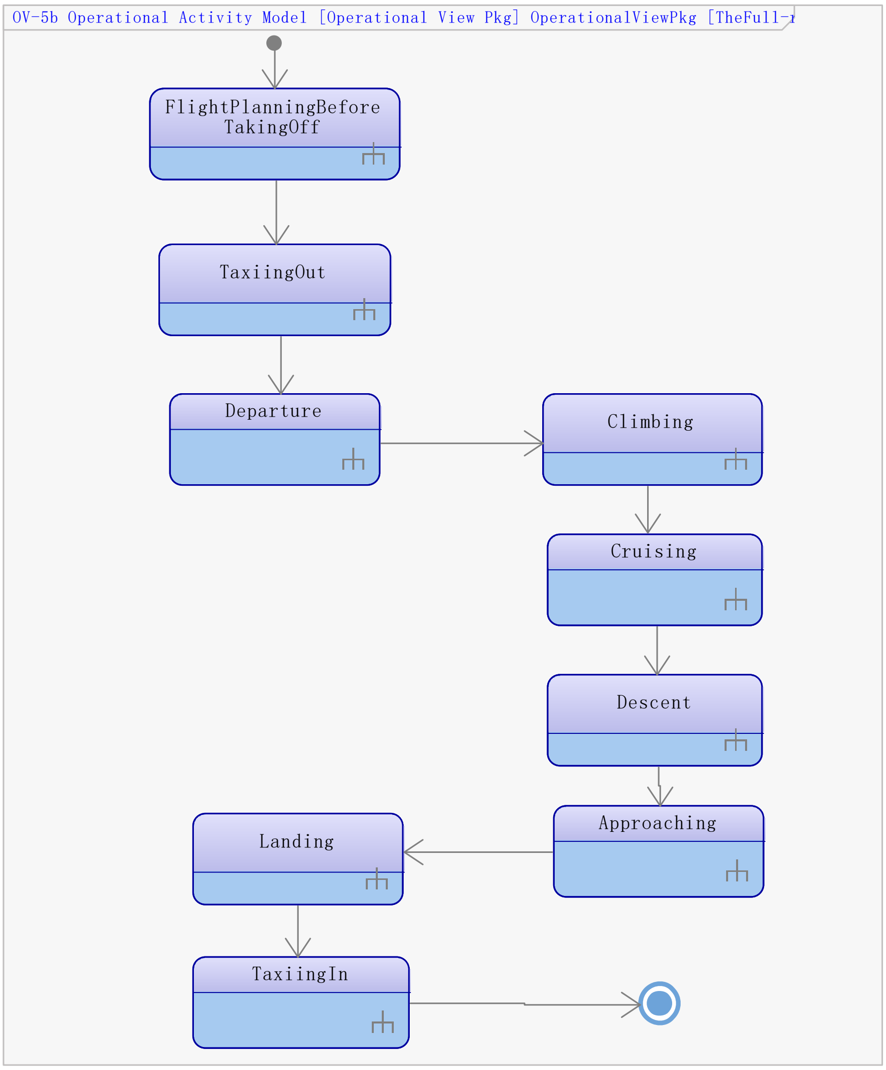

Figure 4.Mission Management Activity Diagram

4.3.1. PRE-DEPARTURE FLIGHT PLANNING

Pre-departure flight planning is an iterative process based on flight schedules, and through collaborative operations among airlines, airports, traffic management and airspace management, the flight trajectory in the planning phase is continuously adjusted based on the latest operational constraints, and finally a feasible flight trajectory is determined before the flight takes off. The model of pre-departure flight planning operation activity diagram is shown in the figure below.

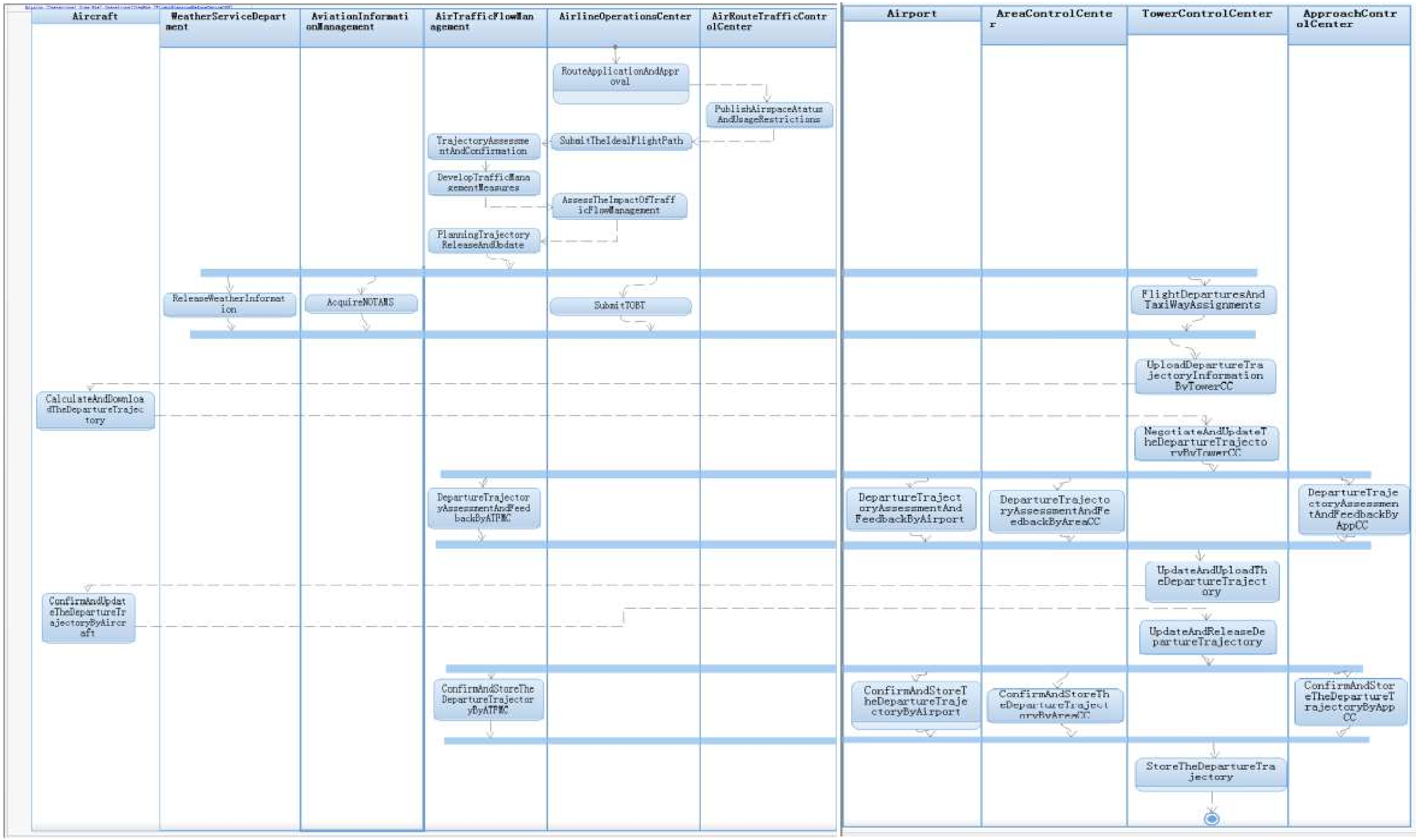

Figure 5. Operational Activity Diagram of Pre-departure Flight Planning Phase

4.3.2. TAXI-OUT

The taxi-out process is a specific procedure in which the flight crew applies for taxi clearance, ATC issues the taxi clearance, and the aircraft follows the designated route to the holding area outside the runway. During this period, the tower control center continuously monitors the conformance of aircraft taxiing trajectory while ATFMC monitors the flow/capacity balancing of airport surface, and the aircraft handles the conflict detection and resolution. Finally, the aircraft arrives at the allocated runway entrance to wait for takeoff. The model of taxi-out operation activity diagram is shown in the figure below.

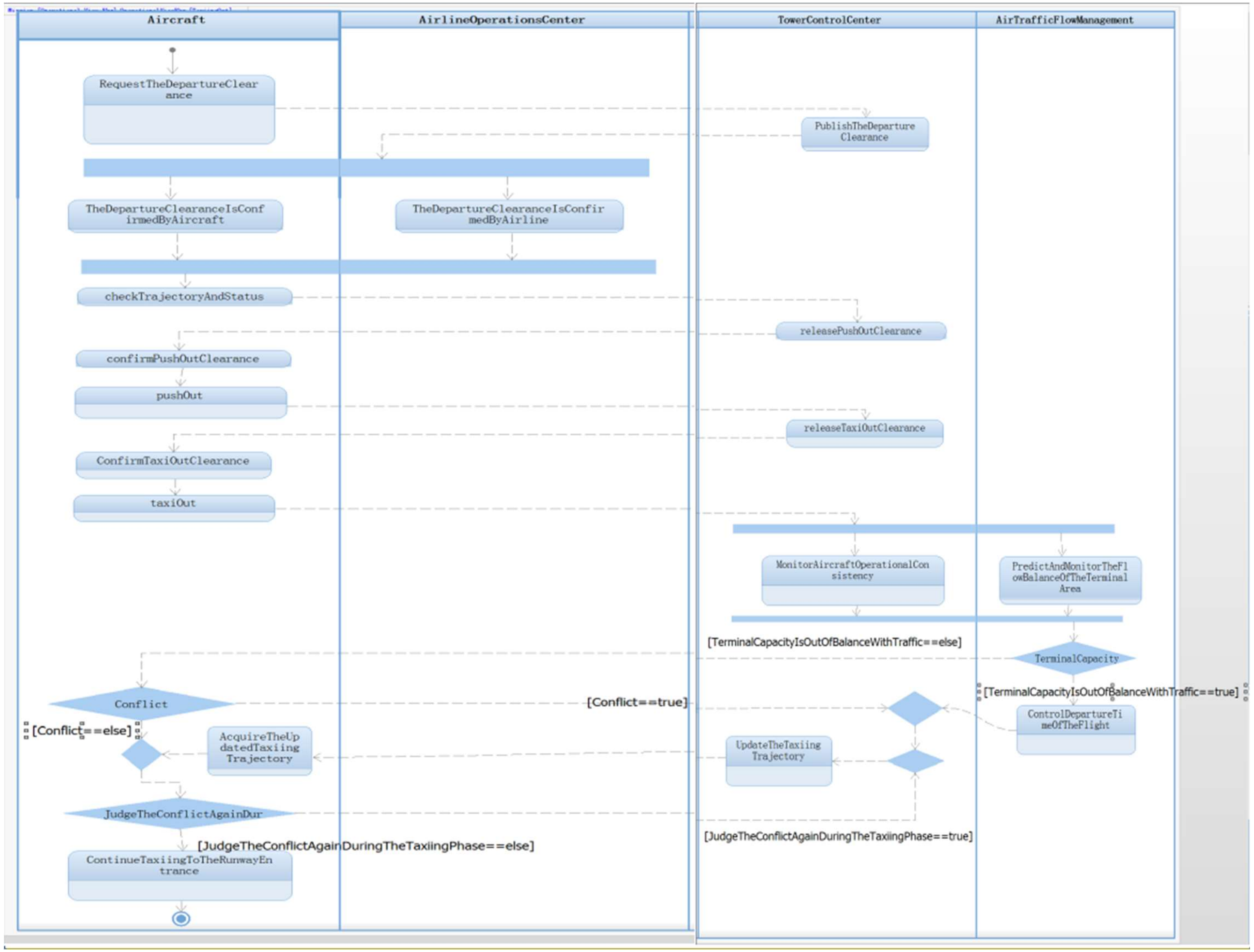

Figure 6. Operational Activity Diagram of Taxi-out Phase

4.3.3. DEPARTURE

The controller confirms the runway is available and issues a takeoff clearance to permit the flight to enter the runway and take off. The flight crew confirms the takeoff clearance and maneuvers the aircraft into the runway and begins to takeoff. The tower control center then hands over the control to the approach control center. The aircraft confirms the control delivery, then joins the departure flow and moves to climb phase. The model of departure operation activity diagram is shown in the figure below.

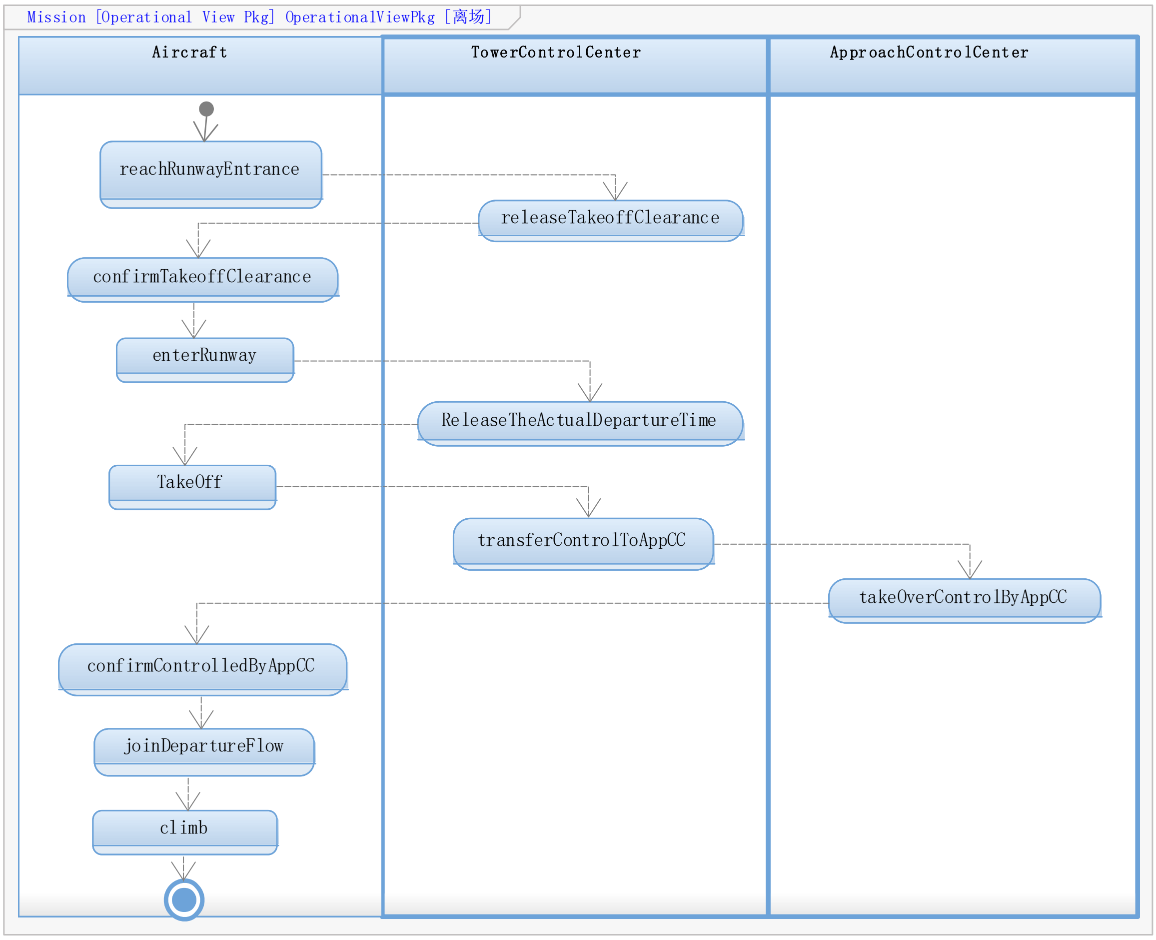

Figure 7. Operational Activity Diagram of Departure Phase

4.3.4. CLIMBING

The aircraft follows the reference trajectory to climb to the cruising altitude, and ATC monitors the trajectory conformance and flight conflict. In case of flight conflict, the approach control center confirms the conflict and performs tactical interval management, issues new control instructions, and updates the reference flight trajectory. The control is handed over to the area control center after the approach control center confirms the flight path altitude, and the aircraft is confirmed of this handover. The model of climbing operation activity diagram is shown in the figure below.

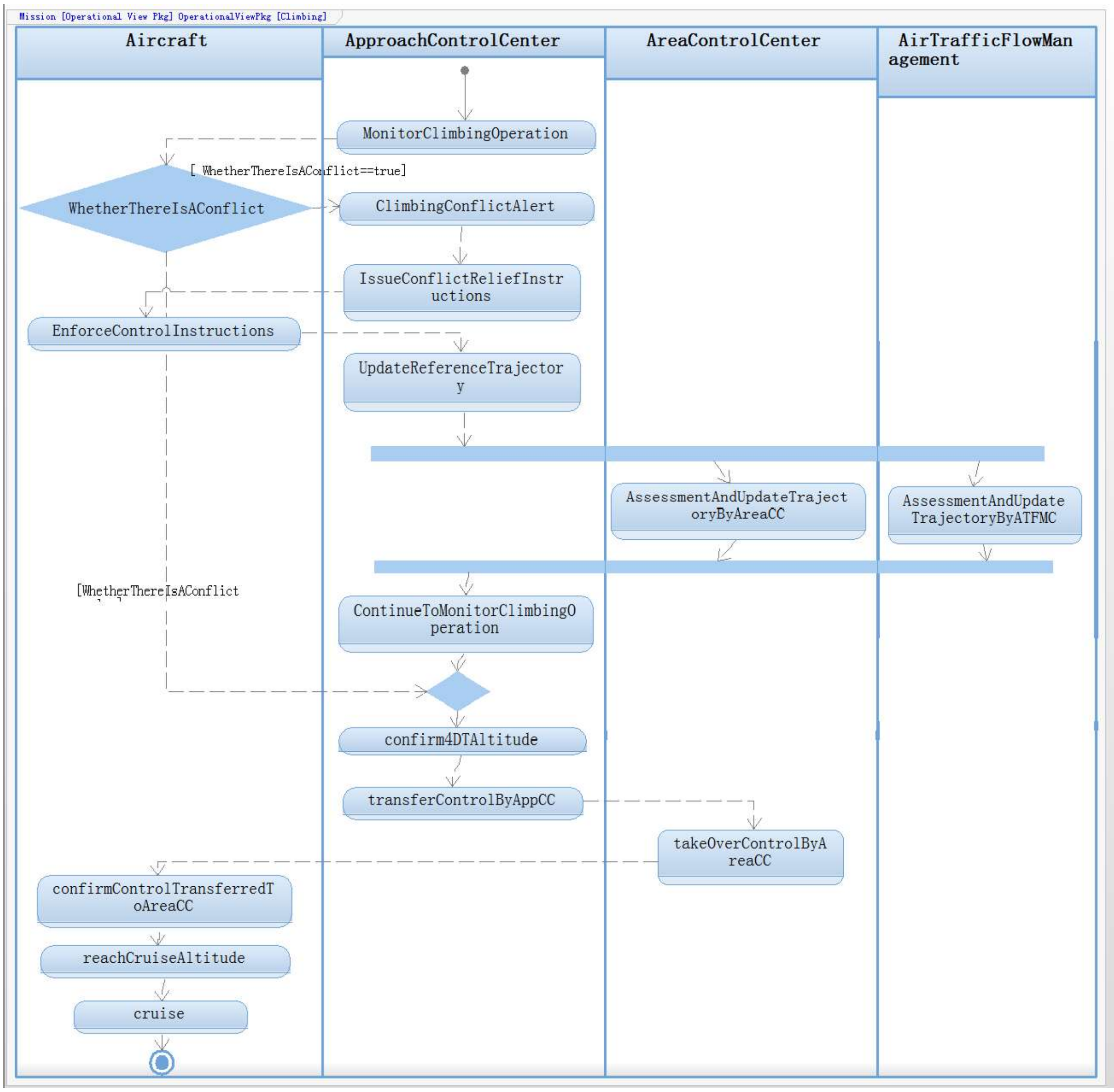

Figure 8. Operational Activity Diagram of Climbing Phase

4.3.5. CRUISING

The aircraft cruises according to the reference trajectory, and ATC monitors the trajectory conformance and flight conflicts. Aircraft can apply to ATC for more fuel-efficient flight level according to actual needs. After receiving the request for flight level change, ATC will judge whether to issue the clearance according to the airspace status. If the clearance is issued, the aircraft will obtain the surrounding aircraft position information through ADS-B-IN and execute the flight level change procedure after receiving the clearance.

Due to uncertainty factors such as meteorology and aircraft execution, if the avionics system detects the existence of potential flight conflict and gives alerts, while automatically generating conflict resolution strategy. The controller confirms the conflict and executes tactical interval management, issues new control instructions, and updates the reference flight trajectory. In the event of a small decrease in capacity in the downstream airspace, the ATFMC takes flow management measures. After receiving the meteorological information released by the AIM, the aircraft judges whether there is meteorological conflict in the downstream trajectory. If the capacity decrease is significant, the ATFMC initiates a collaborative reroute strategy to adjust the reference trajectory, and the aircraft follows the updated trajectory.

The model of cruising operation activity diagram is shown in the figure below.

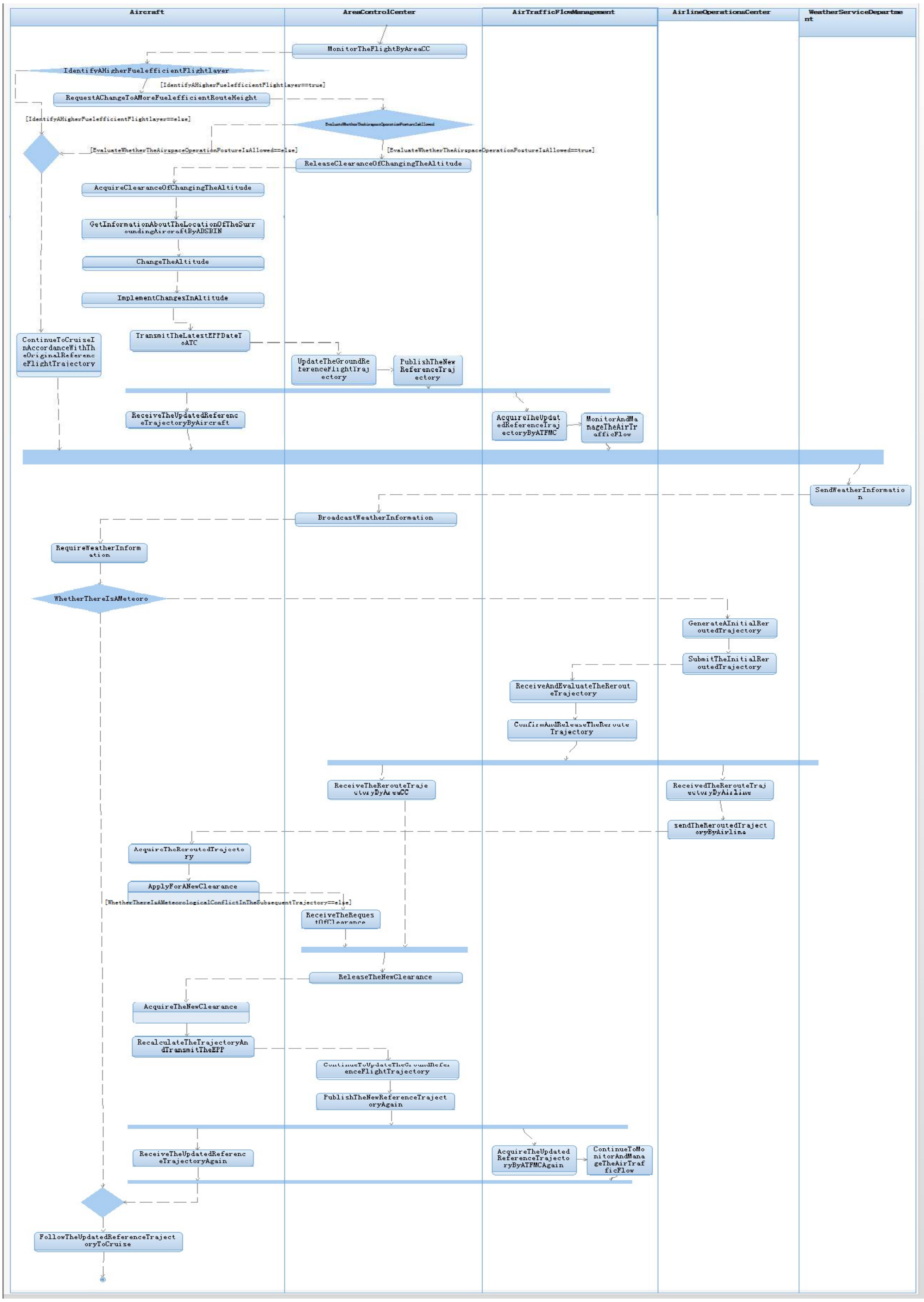

Figure 9. Operational Activity Diagram of Cruising Phase

4.3.6. DESCENT

The aircraft performs continuous descent operations according to the reference flight trajectory, and ATC monitors trajectory conformance and flight conflicts. Due to uncertainty factors such as meteorology and aircraft execution, if the system detects the existence of potential flight conflicts and gives alerts, while automatically generating a conflict resolution strategy; the controller confirms and executes tactical interval management, issues new control instructions, and updates the descent reference trajectory. When the aircraft reaches the control handover altitude, the area control center delivers the control right to the approach control center, and the aircraft confirms the control handover. The model of descent operation activity diagram is shown in the figure below.

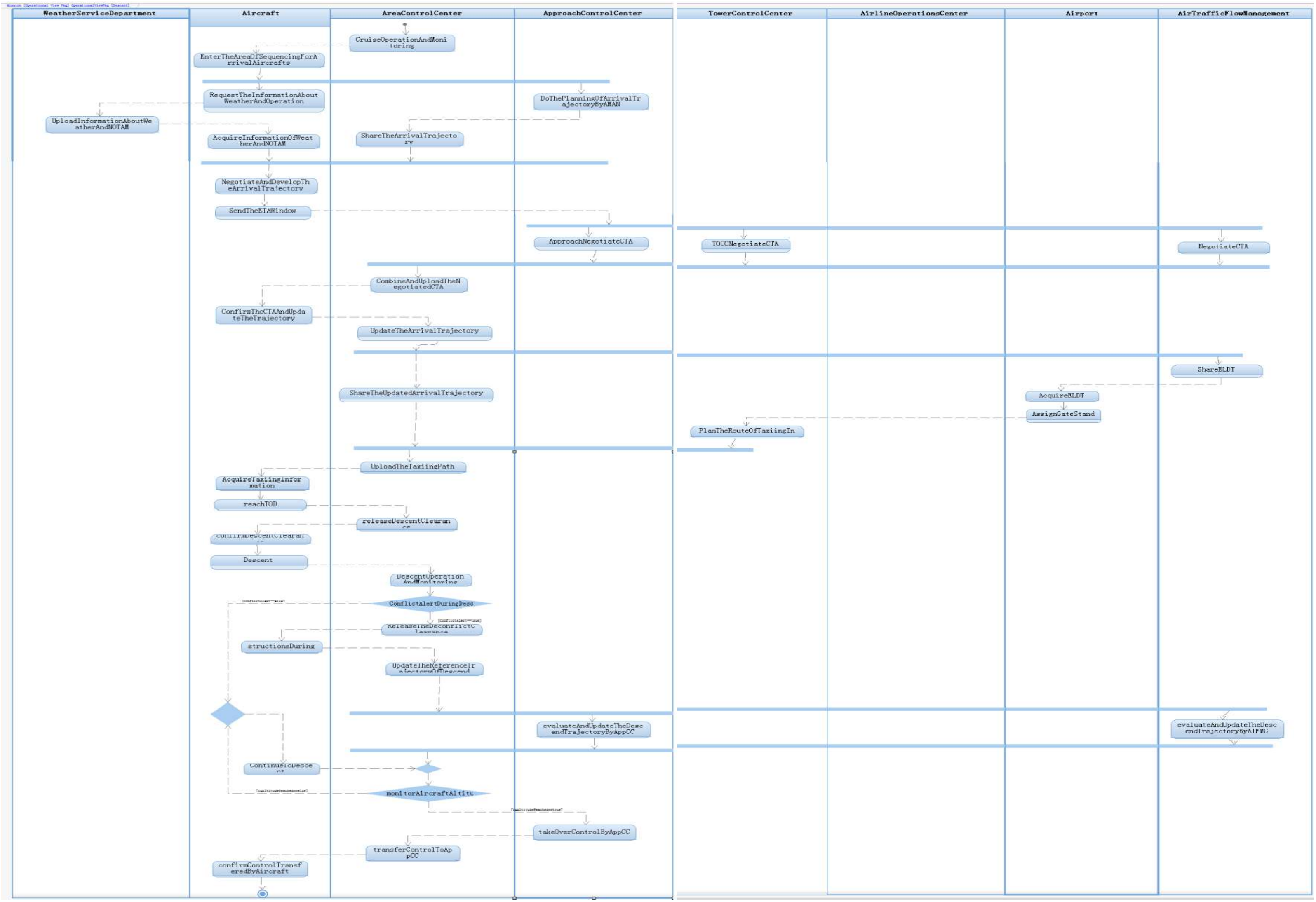

Figure 10. Operational Activity Diagram of Descent Phase

4.3.7. APPROACH

The aircraft obtains the clearance issued by the approach control center to execute the approach procedure, establishes the localizer and glide slope, adjusts the landing attitude, and keeps the operation of the approach procedure through the on-board interval management. The ATC monitors the trajectory conformance and flight conflicts. After the airport updates the gate position, ATC updates the approach taxiway via Surface Manager (SMAN), and uploads the updated taxiway to the aircraft. After approach control center informs the runway weather and surveillance condition, the aircraft completes the final approach and starts to prepare for landing. The model of approach operation activity diagram is shown in the figure below.

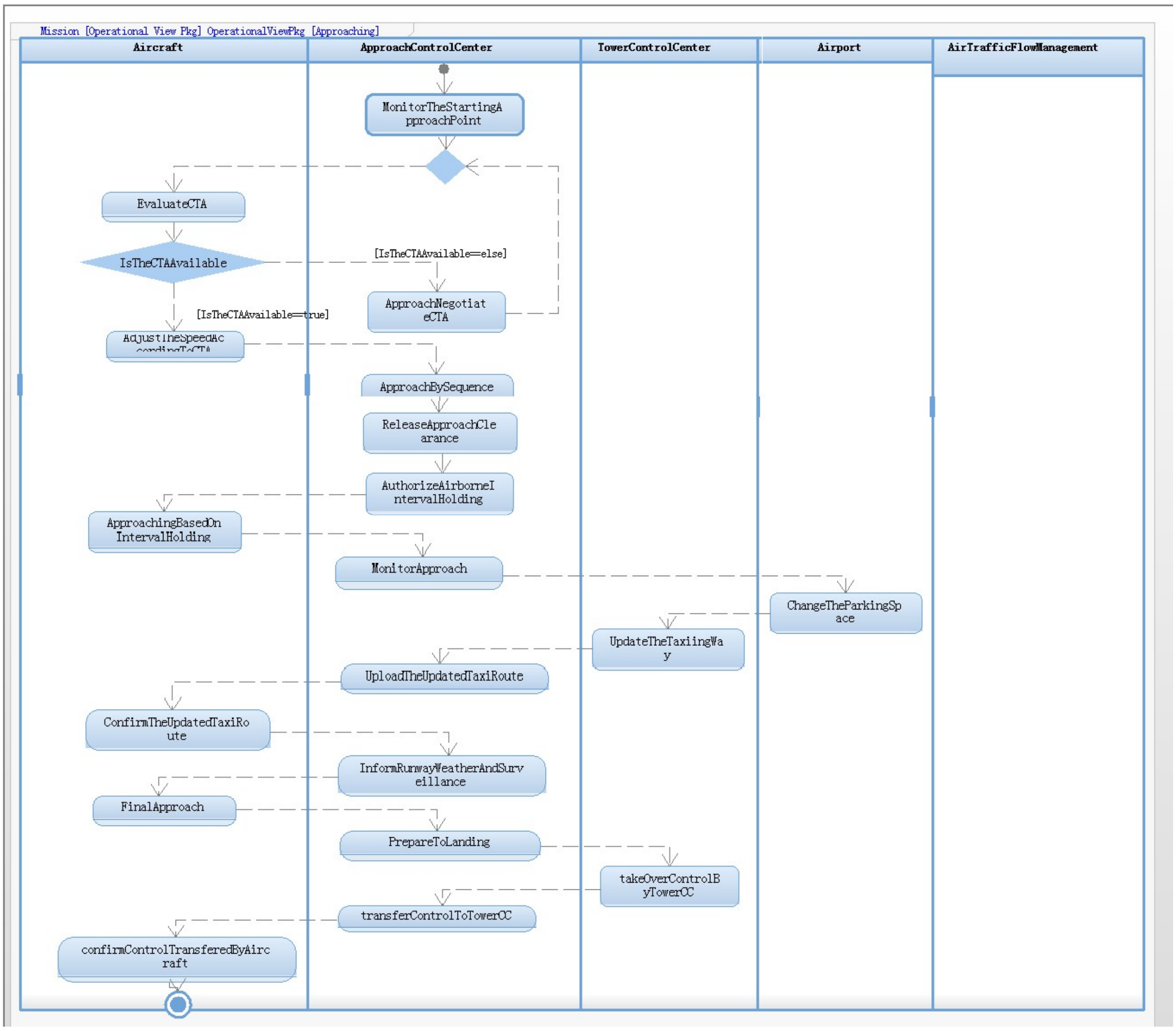

Figure 11. Operational Activity Diagram of Approach Phase

4.3.8. LANDING

When accepting the control handover, the tower control center monitors aircraft operation and confirms runway availability. If available, a landing clearance is issued; if not, the airport needs to reassign the runway, and the aircraft receives the updated runway information. The aircraft receives the landing clearance and completes the landing process to reach the runway end. The model of landing operation activity diagram is shown in the figure below.

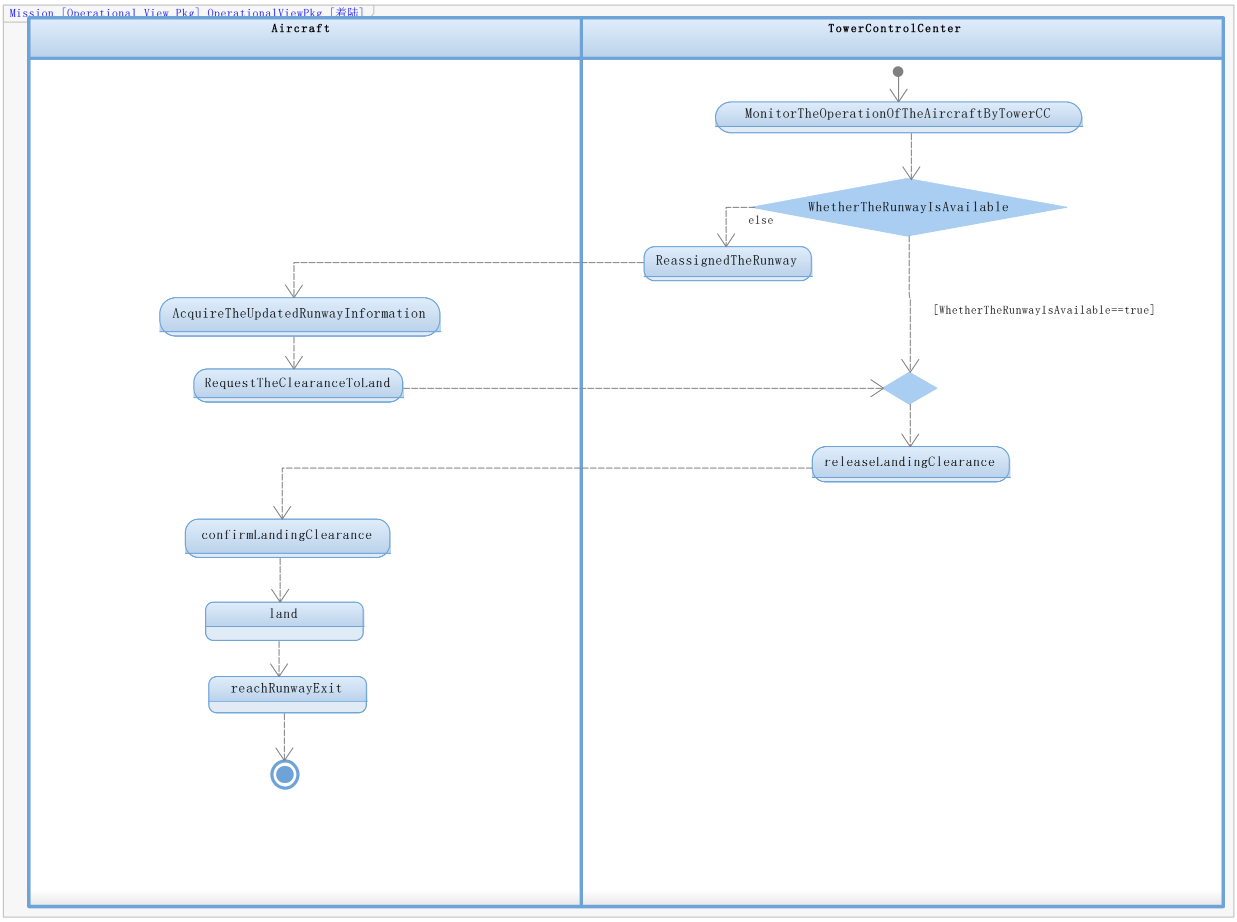

Figure 12. Operational Activity Diagram of Landing Phase

4.3.9. TAXI-IN

Before the aircraft exits the runway, the tower control center issues the taxi-in clearance. The aircraft confirms the clearance and enters the taxiing phase until it arrives at the apron, during which the ATC continuously monitors the aircraft taxiing situation. The model of taxi-in operation activity diagram is shown in the figure below.

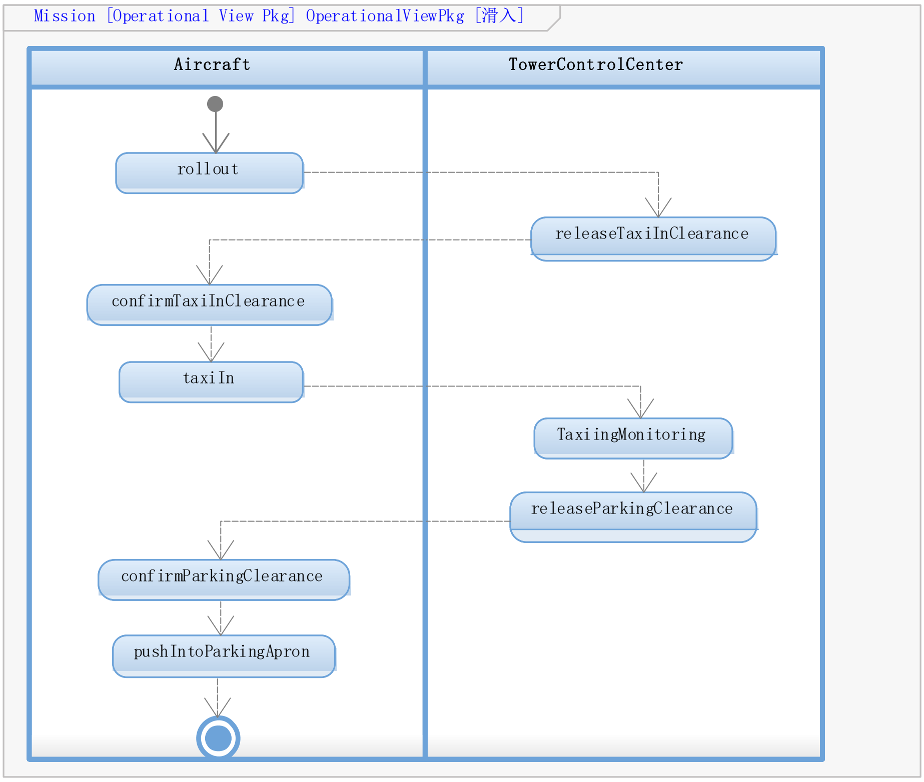

Figure 13. Operational Activity Diagram of Taxi-in Phase

4.4. OPERATIONAL EVENT TRACE DESCRIPTION

Operational Event Trace Description describes the events and timing sequence of operational activities, and describes the dynamic characteristics of nodes. It is implemented by the sequence diagram in SysML. The exchange between system nodes must comply with the causal sequence relationship, that is, under normal circumstances, the external message can only be sent when the trigger signal is received. It is impossible to generate messages and events out of thin air except in special circumstances (such as timing clock trigger signals). From another perspective, the system will perform certain functions to respond after receiving a message, and may send a response signal to the outside world. Such a trigger-response message pair is the input and output of this function. By analyzing each trigger-response pair, the functions performed by the system can be extracted and the corresponding function descriptions can be obtained.

4.4.1. PRE-DEPARTURE FLIGHT PLANNING

The implementation of Pre-departure flight planning relies on the collaboration of Air Traffic Flow Management, Aviation Information Management, Airline Operations Center, Aircraft, Airports, Approach Control Center, Air Route Traffic Control Center, Weather Service Department, Area Control Center and Tower Control Center.

Table 3. Operational event trace description: pre-departure flight planning

Involved Operational Node	Triggered Event	State
AOC	◆ None	❖ Air route application and approval
ARTCC	◆ None	❖ Issuing airspace status and use constraint
AOC	◆ Receiving airspace status and use constraint from ARTCC	❖ Submitting initial flight trajectory
ATFMC	◆ Receiving initial trajectory from AOC	❖ Trajectory evaluation and confirmation
ATFMC	◆ None	❖ Making flow management strategies
ATFMC	◆ None	❖ Sending flow management strategies
AOC	◆ Receiving flow management strategies from ATFMC	❖ Evaluating flow management impact
ATFMC	◆ None	❖ Issuing/updating planned trajectory
WxSD	◆ Receiving planned trajectory issued/updated by ATFMC	❖ Issuing weather information
AIM	◆ None	❖ Sending NOTAMS
AOC	◆ None	❖ Submitting TOBT
TowerCC	◆ Receiving TOBT from AOC	❖ Allocating flight departure and taxi route
	◆ None	❖ Uploading departure trajectory information
Aircraft	◆ Receiving departure trajectory information uploaded by TowerCC	❖ Calculating and downloading departure trajectory

Involved Operational Node	Triggered Event	State
TowerCC	◆ Receiving departure trajectory calculated and downloaded by aircraft	❖ Negotiating departure trajectory with ATFMC
		❖ Negotiating departure trajectory with Airport
		❖ Negotiating departure trajectory with AreaCC
		❖ Negotiating departure trajectory with ApproachCC
ATFMC	◆ None	❖ Evaluating trajectory and sending feedback
Airport	◆ None	❖ Evaluating trajectory and sending feedback
AreaCC	◆ None	❖ Evaluating trajectory and sending feedback
ApproachCC	◆ None	❖ Evaluating trajectory and sending feedback
TowerCC	◆ Acquiring trajectory evaluation from other stakeholders	❖ Updating and uploading departure trajectory
Aircraft	◆ Receiving departure trajectory updated and uploaded by TowerCC	❖ Confirming and updating departure trajectory
TowerCC	◆ None	❖ Updating and publishing departure trajectory
AreaCC	◆ None	❖ Confirming and storing departure trajectory
ApproachCC	◆ None	❖ Confirming and storing departure trajectory
Airport	◆ None	❖ Confirming and storing departure trajectory

Involved Operational Node	Triggered Event	State
ATFMC	◆ None	❖ Confirming and storing departure trajectory

4.4.2. TAXI-OUT

The implementation of Taxi-out relies on the collaboration of Air Traffic Flow Management, Airline Operations Center, Aircraft and Tower Control Center.

Table 4. Operational event trace description: taxi-out

Involved Operational Node	Triggered Event	State
Aircraft	◆ None	❖ Requiring departure clearance
TowerCC	◆ Receiving departure clearance request from aircraft	❖ Issuing departure clearance
Aircraft	◆ Receiving departure clearance	❖ Confirming departure clearance
AOC	◆ None	❖ Confirming departure clearance
Aircraft	◆ None	❖ Checking trajectory and aircraft status
TowerCC	◆ None	❖ Issuing pushback clearance
Aircraft	◆ Receiving pushback clearance	❖ Confirming pushback clearance
	◆ None	❖ Pushing back
TowerCC	◆ None	❖ Issuing taxi-out clearance
Aircraft	◆ Receiving taxi-out clearance	❖ Confirming taxi-out clearance
	◆ None	❖ Taxiing out

Involved Operational Node	Triggered Event		State
TowerCC	◆ None		❖ Monitoring conformance of aircraft taxi operation
ATFMC	◆ None		❖ Predicting and monitoring terminal capacity/flow balancing
	◆ Judgement Event	◆ If capacity and flow is balanced	❖ None
		◆ If capacity and flow is unbalanced	❖ Adjusting departure time of aircraft
Aircraft	◆ Judgement Event	◆ If no conflict is detected	❖ Keep taxiing out
		◆ If a conflict is detected	❖ Sending conflict alert to TowerCC
TowerCC	◆ Receiving conflict alert		❖ Updating taxi trajectory
Aircraft	◆ Receiving updated taxi trajectory		❖ Keep taxiing to the runway entrance

4.4.3. DEPARTURE

The implementation of Departure relies on the collaboration of Aircraft, Approach Control Center and Tower Control Center.

Table 5. Operational event trace description: departure

Involved Operational Node	Triggered Event	State
Aircraft	◆ None	❖ Arriving at runway entrance
TowerCC	◆ None	❖ Issuing takeoff clearance
Aircraft	◆ Receiving takeoff clearance	❖ Confirming takeoff clearance

Involved Operational Node	Triggered Event	State
	◆ None	❖ Entering the runway
TowerCC	◆ None	❖ Issuing ATOT
Aircraft	◆ Acquiring ATOT from TowerCC	❖ Taking off
TowerCC	◆ None	❖ Handing over flight control
ApproachCC	◆ Accepting control handover from TowerCC	❖ Controlling the flight
Aircraft	◆ Confirming the control handover	❖ Joining departure flow
	◆ None	❖ Begin climbing

4.4.4. CLIMBING

The implementation of Climbing relies on the collaboration of Air Traffic Flow Management Center, Aircraft, Approach Control Center and Area Control Center.

Table 6. Operational event trace description: climbing

<table>
<tr><th>Involved Operational Node</th><th colspan="2">Triggered Event</th><th>State</th></tr>
<tr><td>ApproachCC</td><td colspan="2">◆ None</td><td>❖ Monitoring climbing operation</td></tr>
<tr><td rowspan="2">Aircraft</td><td rowspan="2">◆ Judgement Event</td><td>◆ If no conflict is detected</td><td>❖ Keep climbing as planned</td></tr>
<tr><td>◆ If a conflict is detected</td><td>❖ Sending climbing conflict alert</td></tr>
<tr><td>ApproachCC</td><td colspan="2">◆ Receiving climbing conflict alert from aircraft</td><td>❖ Issuing resolution instruction</td></tr>
<tr><td>Aircraft</td><td colspan="2">◆ Receiving resolution instruction</td><td>❖ Executing the instruction</td></tr>
<tr><td rowspan="2">ApproachCC</td><td colspan="2">◆ None</td><td>❖ Updating reference trajectory</td></tr>
<tr><td colspan="2">◆ None</td><td>❖ Sending updated reference trajectory to AreaCC</td></tr>
</table>

Involved Operational Node	Triggered Event	State
	◆ None	❖ Sending updated reference trajectory to ATFMC
AreaCC	◆ Receiving updated reference trajectory	❖ Evaluating and updating trajectory
ATFMC	◆ Receiving updated reference trajectory	❖ Evaluating and updating trajectory
ApproachCC	◆ None	❖ Keep monitoring climbing operation
	◆ None	❖ Confirming flight altitude
	◆ The aircraft reaches the altitude for control handover	❖ Handing over flight control
AreaCC	◆ Accepting control handover from ApproachCC	❖ Controlling the flight
Aircraft	◆ None	❖ Confirming the control handover
	◆ Reaching the altitude for control handover	❖ Begin cruising

4.4.5. CRUISING

The implementation of Cruising relies on the collaboration of Air Traffic Flow Management Center, Airline Operation Center, Aircraft, Weather Service Department and Area Control Center.

Table 7. Operational event trace description: cruising

Involved Operational Node	Triggered Event		State
AreaCC	◆ None		❖ Monitoring cruising operation
Aircraft	◆ Judgement Event	◆ If a more fuel-saving flight level is not identified	❖ keep cruising as planned

Involved Operational Node	Triggered Event		State
		◆ If a more fuel-saving flight level is identified	❖ Requiring change to more fuel-saving flight level
AreaCC	◆ Judgement Event	◆ If the airspace condition does not permit	❖ Rejecting flight level change request
		◆ If the airspace condition permits	❖ Issuing flight level change clearance
Aircraft	◆ Receiving flight level change clearance		❖ Acquiring position information of surrounding aircraft via ADS-B
	◆ None		❖ Executing flight level change
	◆ None		❖ Downloading updated EPP data
AreaCC	◆ Receiving EPP data downloaded by aircraft		❖ Updating ground reference trajectory
	◆ None		❖ Issuing updated reference trajectory to Aircraft
	◆ None		❖ Issuing updated reference trajectory to ATFMC
ATFMC	◆ None		❖ Monitoring and managing traffic flow
Aircraft	◆ None		❖ Keep cruising according to reference trajectory

Involved Operational Node	Triggered Event		State
WxSD	◆ None		❖ Sending weather information
AreaCC	◆ None		❖ Broadcasting weather information
Aircraft	◆ Receiving weather information		❖ Judging if there is weather conflict in the downstream trajectory
	◆ Judgement Event	◆ If no weather conflict is detected	❖ Keep cruising according to reference trajectory
		◆ If a weather conflict in the downstream trajectory is detected	❖ Generating initial reroute trajectory
AOC	◆ None		❖ Submitting initial reroute trajectory
ATFMC	◆ Receiving reroute trajectory		❖ Receiving and evaluating reroute trajectory
	◆ None		❖ Confirming and sending reroute trajectory to AreaCC
	◆ None		❖ Confirming and sending reroute trajectory to AOC
AreaCC	◆ None		❖ Receiving reroute trajectory
AOC	◆ None		❖ Receiving reroute trajectory

Involved Operational Node	Triggered Event	State
	◆ None	❖ Receiving reroute trajectory
Aircraft	◆ Receiving reroute trajectory	❖ Applying for new clearance
AreaCC	◆ Receiving new clearance request	❖ Issuing new clearance
Aircraft	◆ Receiving new clearance	❖ Recomputing trajectory and downloading EPP data
AreaCC	◆ Receiving EPP data from aircraft	❖ Updating ground reference trajectory
	◆ None	❖ Sending new reference trajectory to Aircraft
	◆ None	❖ Sending new reference trajectory to ATFMC
ATFMC	◆ None	❖ Monitoring and managing traffic flow
Aircraft	◆ None	❖ Cruising according to new reference trajectory

4.4.6. DESCENT

The implementation of Descent relies on the collaboration of Air Traffic Flow Management Center, Airline Operation Center, Aircraft, Airport, Weather Service Department, Tower Control Center, Approach Control Center and Area Control Center.

Table 8. Operational event trace description: descent

Involved Operational Node	Triggered Event	State
AreaCC	◆ None	❖ Monitoring cruising operation

Involved Operational Node	Triggered Event	State
Aircraft	◆ Entering approach sequencing management area	❖ Requiring weather information
ApproachCC	◆ None	❖ Planning approach trajectory
AreaCC	◆ None	❖ Sharing approach trajectory
WxSD	◆ None	❖ Uploading weather information
Aircraft	◆ Receiving weather information	❖ Generating approach trajectory
	◆ None	❖ Downloading ETA window
ApproachCC	◆ Receiving ETA window from aircraft	❖ Negotiating CTA
TowerCC	◆ Receiving ETA window from aircraft	❖ Negotiating CTA
ATFMC	◆ Receiving ETA window from aircraft	❖ Negotiating CTA
AreaCC	◆ Receiving CTA negotiated by all involved stakeholders	❖ Integrating and uploading negotiated CTA
Aircraft	◆ None	❖ Confirming CTA and updating trajectory
AreaCC	◆ None	❖ Updating approach trajectory
	◆ None	❖ Sharing updated approach trajectory
ATFMC	◆ None	❖ Sharing ELDT
Airport	◆ Receiving ELDT from ATFMC	❖ Allocating apron
TowerCC	◆ Acquiring allocated apron information	❖ Planning approach taxi trajectory

<table>
<tr><th>Involved Operational Node</th><th colspan="2">Triggered Event</th><th>State</th></tr>
<tr><td>AreaCC</td><td colspan="2">◆ None</td><td>❖ Uploading approach taxi trajectory</td></tr>
<tr><td rowspan="2">Aircraft</td><td colspan="2">◆ None</td><td>❖ Receiving surface taxi information</td></tr>
<tr><td colspan="2">◆ None</td><td>❖ Reaching TOD</td></tr>
<tr><td>AreaCC</td><td colspan="2">◆ Aircraft reaches TOD</td><td>❖ Issuing descent clearance</td></tr>
<tr><td>Aircraft</td><td colspan="2">◆ Confirming descent clearance</td><td>❖ Begin Descending</td></tr>
<tr><td rowspan="3">AreaCC</td><td colspan="2">◆ None</td><td>❖ Monitoring descent operation</td></tr>
<tr><td rowspan="2">◆ Judgement Event</td><td>◆ If no conflict is detected</td><td>❖ Keep monitoring descent operation</td></tr>
<tr><td>◆ If a conflict is detected</td><td>❖ Issuing conflict resolution instruction</td></tr>
<tr><td>Aircraft</td><td colspan="2">◆ Receiving resolution instruction</td><td>❖ Executing resolution instruction</td></tr>
<tr><td>AreaCC</td><td colspan="2">◆ None</td><td>❖ Updating descent reference trajectory</td></tr>
<tr><td>Aircraft</td><td colspan="2">◆ Resolution completed</td><td>❖ Keep descending</td></tr>
<tr><td>ApproachCC</td><td colspan="2">◆ Receiving updated descent reference trajectory</td><td>❖ Evaluating and updating descent trajectory</td></tr>
<tr><td>ATFMC</td><td colspan="2">◆ Receiving updated descent reference trajectory</td><td>❖ Evaluating and updating descent trajectory</td></tr>
<tr><td>AreaCC</td><td colspan="2">◆ Aircraft reaches control handover altitude</td><td>❖ Handing over control to ApproachCC</td></tr>
<tr><td>ApproachCC</td><td colspan="2">◆ Accepting control handover</td><td>❖ Controlling the flight</td></tr>
<tr><td>Aircraft</td><td colspan="2">◆ None</td><td>❖ Confirming the control handover</td></tr>
</table>

4.4.7. APPROACH

The implementation of Approach relies on the collaboration of Aircraft, Airport, Tower Control Center and Approach Control Center.

Table 9. Operational event trace description: approach

Involved Operational Node	Triggered Event		State
ApproachCC	◆ None		❖ Monitoring initial approach fix
Aircraft	◆ None		❖ Evaluating CTA
	◆ Judgement Event	◆ CTA is available	❖ Keep initial CTA
		◆ CTA is not available	❖ Negotiating CTA
	◆ None		❖ Adjusting speed according to CTA
ApproachCC	◆ None		❖ Sequencing approach traffic
	◆ None		❖ Issuing approach clearance
	◆ None		❖ Authorizing airborne flight interval management
Aircraft	◆ Acquiring approach clearance		❖ Approaching while maintaining flight interval
ApproachCC	◆ None		❖ Monitoring the approach
Airport	◆ None		❖ Updating apron
TowerCC	◆ None		❖ Updating arrival taxi route
ApproachCC	◆ Acquiring updated arrival taxi route		❖ Uploading updated taxi route
Aircraft	◆ None		❖ Confirming updated taxi route
ApproachCC	◆ Aircraft confirms updated taxi route		❖ Publishing runway meteorological information
Aircraft	◆ Acquiring runway meteorological information		❖ Conducting final approach
ApproachCC	◆ Aircraft complete final approach		❖ Preparing for landing
TowerCC	◆ Receiving control handover from ApproachCC		❖ Accepting the control handover

Involved Operational Node	Triggered Event	State
Aircraft	◆ None	❖ Confirming the control handover

4.4.8. LANDING

The implementation of Landing relies on the collaboration of Aircraft and Tower Control Center.

Table 10. Operational event trace description: landing

Involved Operational Node	Triggered Event		State
TowerCC	◆ None		❖ Monitoring the landing aircraft
	Judgement Event	Runway is available	Keep landing
		Runway is not available	Requiring Airport to reallocate runway
Aircraft	Receiving updated runway information		Requiring landing clearance
TowerCC	◆ Receiving landing clearance request		❖ Issuing landing clearance
Aircraft	Confirming landing clearance		Landing
	None		Reaching runway exit

4.4.9. TAXI-IN

The implementation of Taxi-in relies on the collaboration of Aircraft and Tower Control Center.

Table 11. Operational event trace description: taxi-in

Involved Operational Node	Triggered Event	State
Aircraft	◆ None	❖ Exiting runway
TowerCC	◆ Aircraft exit runway	❖ Issuing taxi-in clearance
Aircraft	◆ Confirming taxi-in clearance	❖ Taxiing in
TowerCC	◆ None	❖ Monitoring the taxi
	◆ Aircraft arrives at allocated apron	❖ Issuing parking clearance

Involved Operational Node	Triggered Event	State
Aircraft	◆ Confirming parking clearance	❖ Entering apron

4.5. OPERATIONAL STATE TRANSITION DESCRIPTION

Operational State Transition Description is implemented in SysML state diagrams, which emphasize the dynamic behavior of the system. It is the basis for generating executable models. Its basic elements include states, transfers, events, and operations. Each pair of trigger-response messages on the sequence diagram and the activities executed in between corresponds to a transfer on the state machine. There must be a state between adjacent transfers, and the representation of these states completes a state machine.

4.5.1. AIR TRAFFIC FLOW MANAGEMENT CENTER

Air Traffic Flow Management Center participates in multiple operation phases as one of the operational nodes. The triggering events, state transitions and response events are shown in the following state diagram.

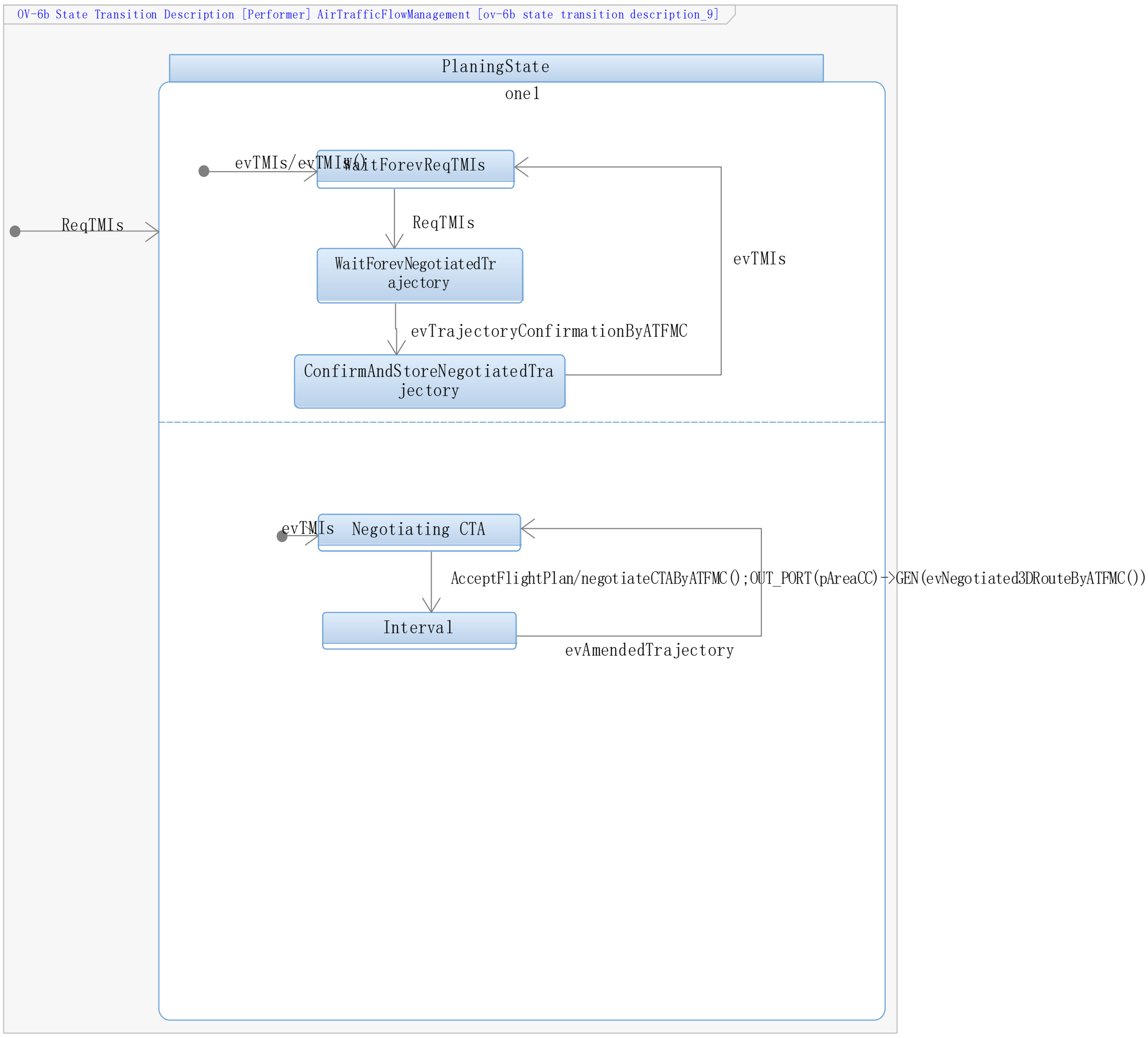

Figure 14. Operational State Transition Description of Air Traffic Flow Management Center

4.5.2. AVIATION INFORMATION MANAGEMENT

Aviation Information Management participates in multiple operation phases as one of the operational nodes. The triggering events, state transitions and response events are shown in the following state diagram.

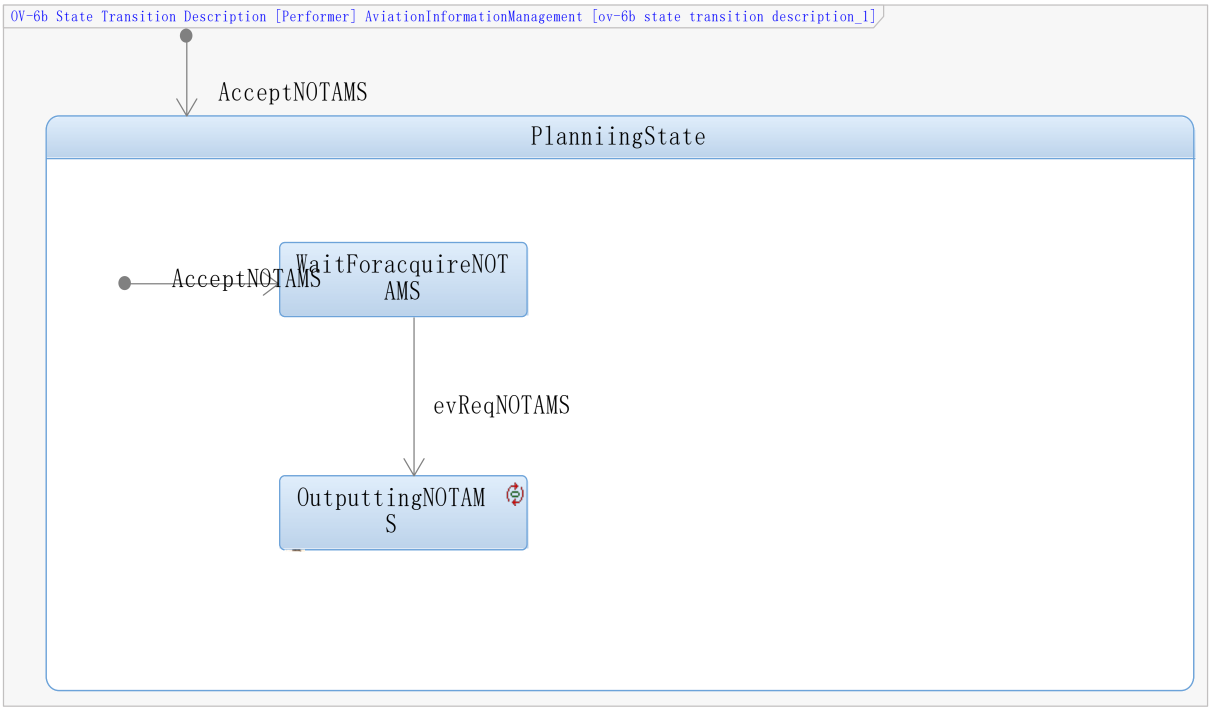

Figure 15. Operational State Transition Description of Aviation Information Management

4.5.3. AIRLINE

Airline participates in multiple operation phases as one of the operational nodes. The triggering events, state transitions and response events are shown in the following state diagram.

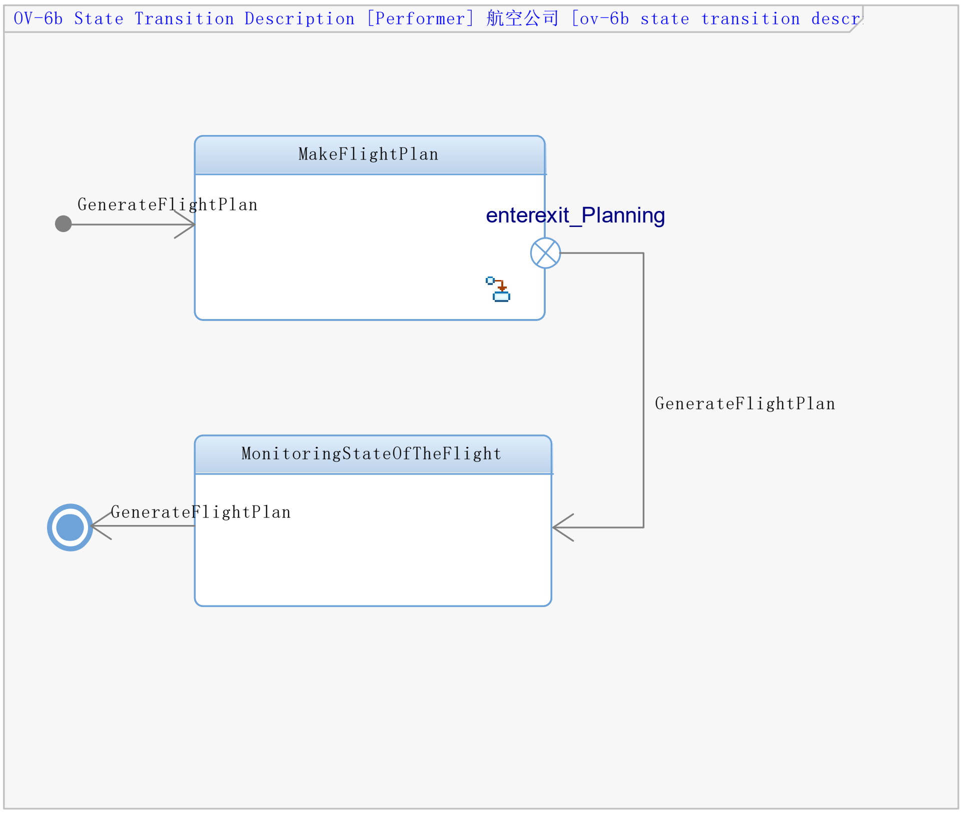

Figure 16. Operational State Transition Description of Airline

4.5.4. AIRCRAFT

Aircraft participates in multiple operation phases as one of the operational nodes. The triggering events, state transitions and response events are shown in the following state diagram.

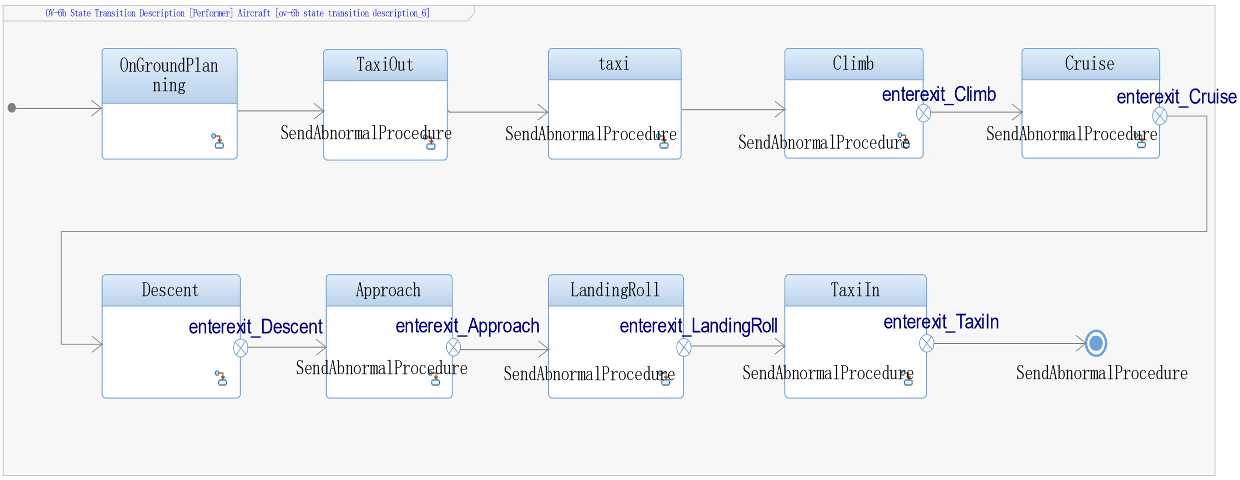

Figure 17. Operational State Transition Description of Aircraft

4.5.5. AIRPORT

Airport participates in multiple operation phases as one of the operational nodes. The triggering events, state transitions and response events are shown in the following state diagram.

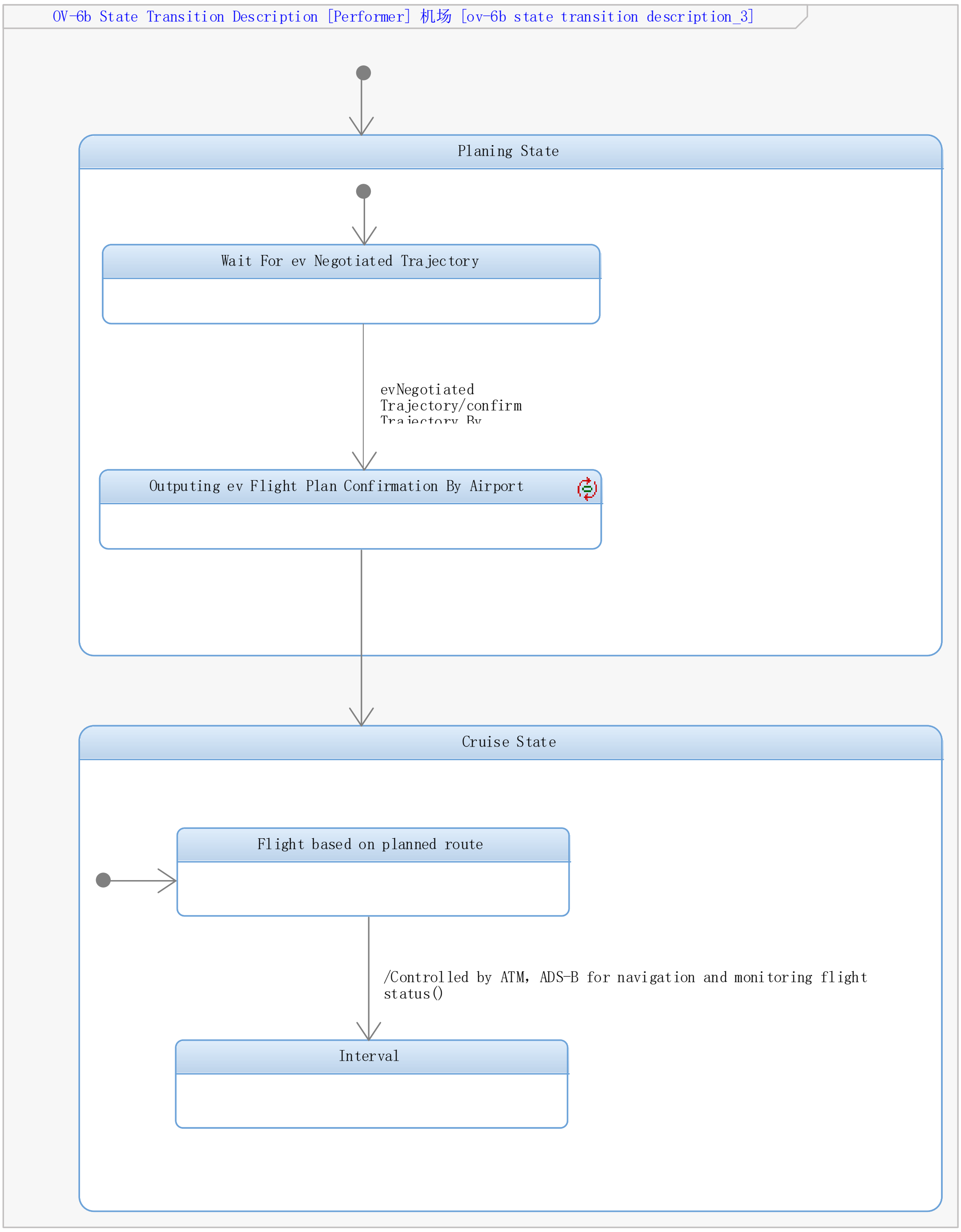

Figure 18. Operational State Transition Description of Airport

4.5.6. APPROACH CONTROL CENTER

Approach Control Center participates in multiple operation phases as one of the operational nodes. The triggering events, state transitions and response events are shown in the following state diagram.

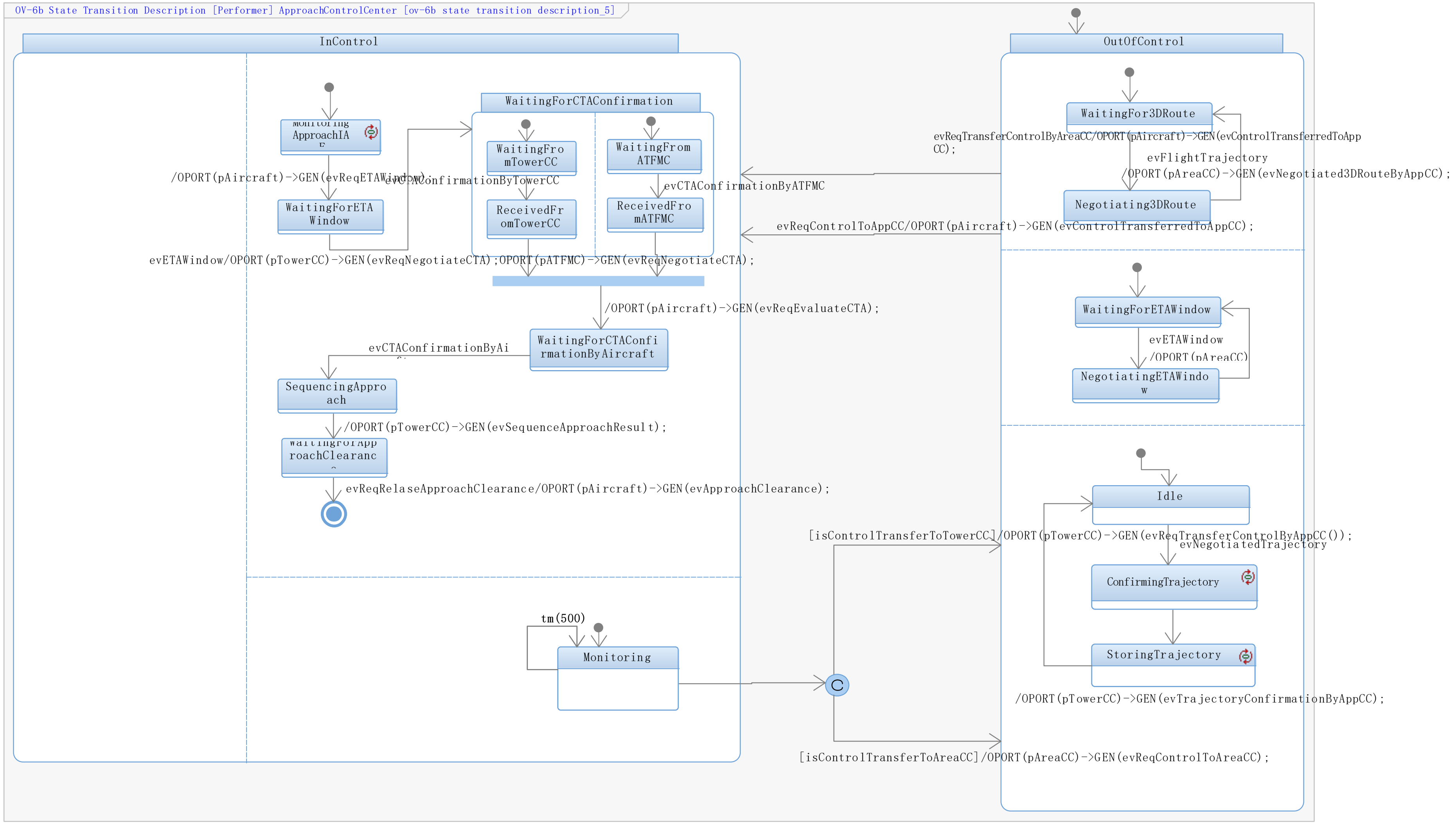

Figure 19. Operational State Transition Description of Approach Control Center

4.5.7. AIR ROUTE TRAFFIC CONTROL CENTER

Air Route Traffic Control Center participates in multiple operation phases as one of the operational nodes. The triggering events, state transitions and response events are shown in the following state diagram.

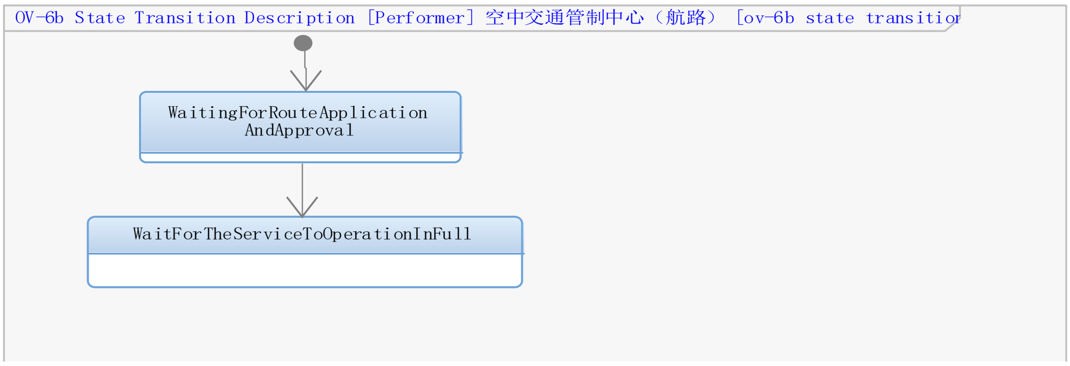

Figure 20. Operational State Transition Description of Air Route Traffic Control Center

4.5.8. WEATHER SERVICE DEPARTMENT

Weather Service Department participates in multiple operation phases as one of the operational nodes. The triggering events, state transitions and response events are shown in the following state diagram.

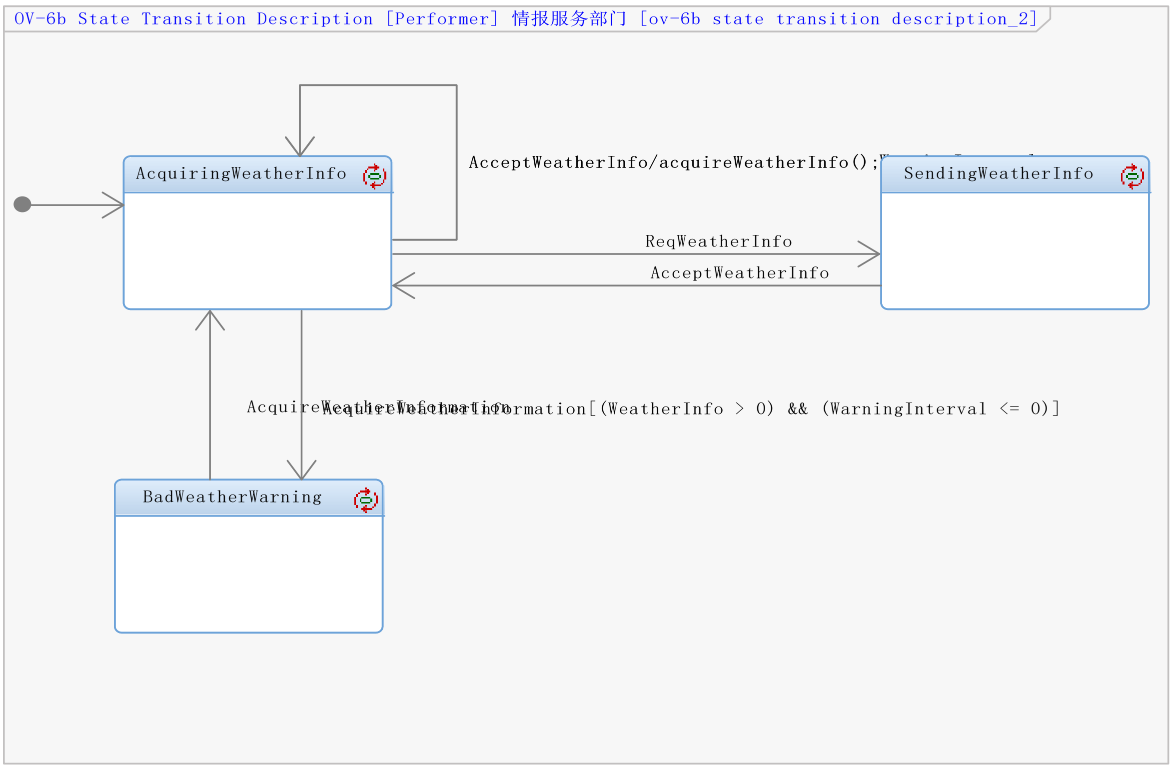

Figure 21. Operational State Transition Description of Weather Service Department

4.5.9. AREA CONTROL CENTER

Area Control Center participates in multiple operation phases as one of the operational nodes. The triggering events, state transitions and response events are shown in the following state diagram.

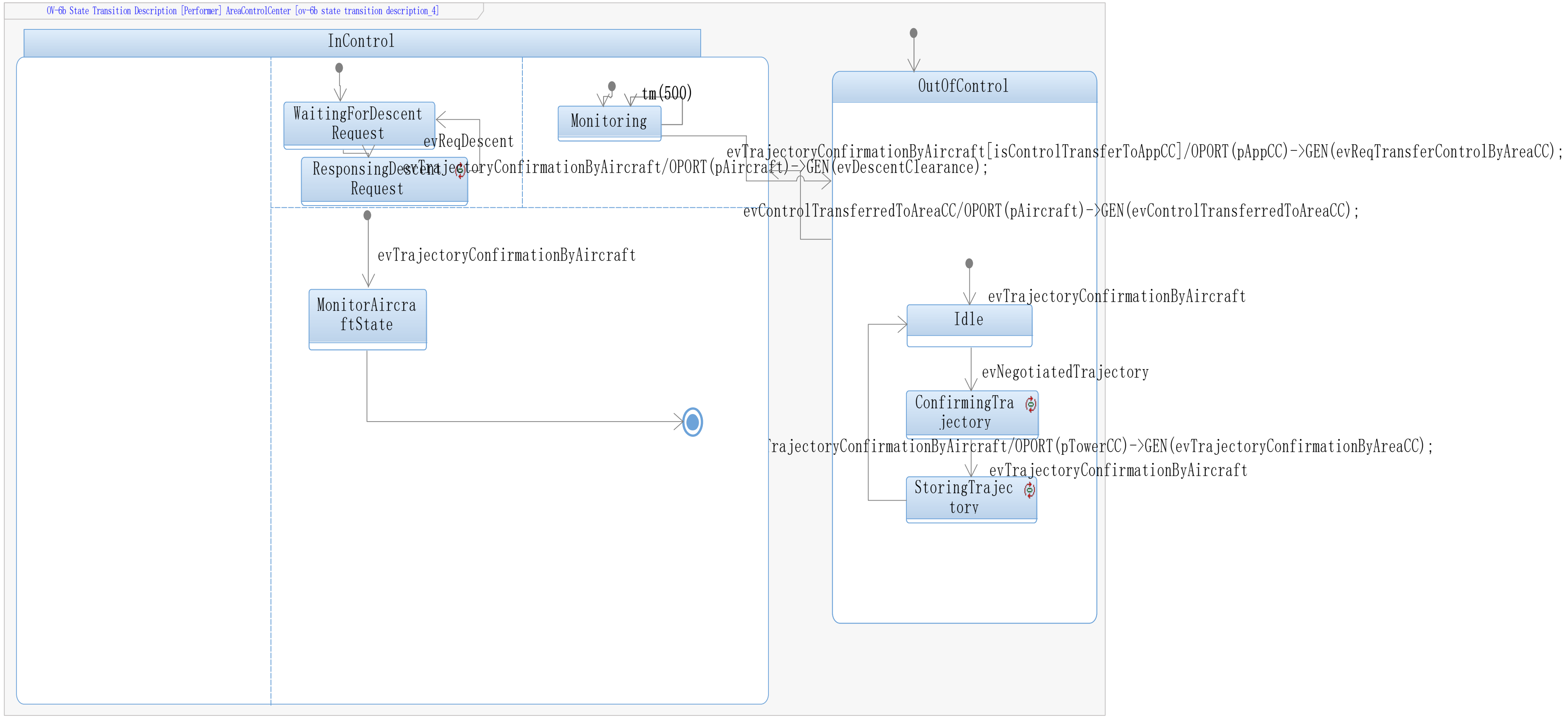

Figure 22. Operational State Transition Description of Area Control Center

4.5.10. TOWER CONTROL CENTER

Tower Control Center participates in multiple operation phases as one of the operational nodes. The triggering events, state transitions and response events are shown in the following state diagram.

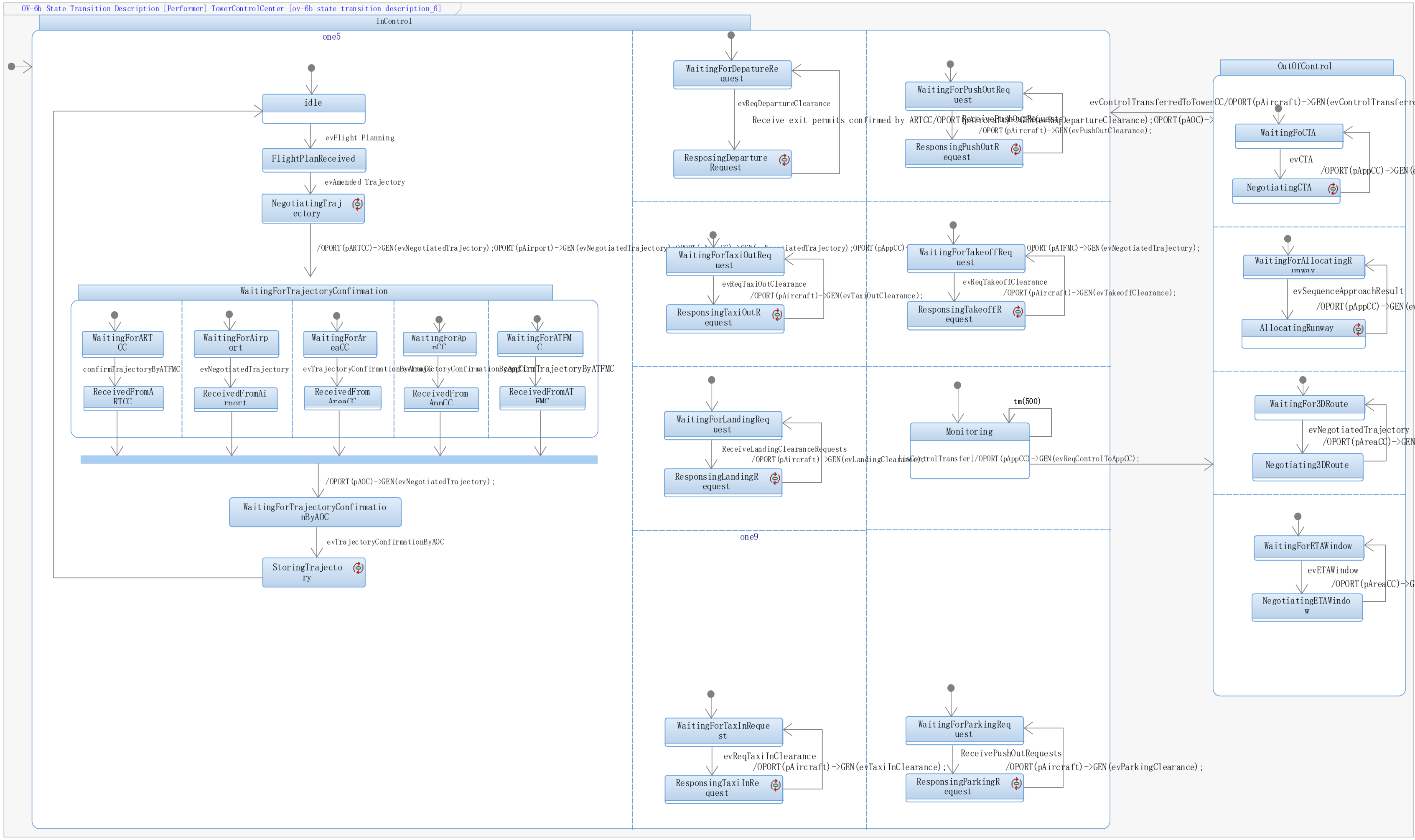

Figure 23. Operational State Transition Description of Tower Control Center

5. DETAILED DESIGN OF SYSTEM ARCHITECTURE

5.1. SYSTEM FUNCTIONALITY DESCRIPTION

In this section, the operational activities analyzed in the operational view are mapped to the corresponding system functions, which are assigned to the actual systems. The description of the relationship between the system functions is illustrated in the System Functionality Description. It defines system functionality supporting operational activities, and establishes the mapping from operational activities to system interface description and allocation of system functions into sub-systems. These system functions will eventually evolve to system requirements supporting operation, guiding system-level development.

Table 12. System functionality description

No.	Information transferred and functions	Node	System
1	Send/acquire ADS-B (surrounding aircraft), MCDU 、 EICAS 、 altitude change request 、 detour request 、 confirmation of conflict resolution instructions、 weather information reception 、 reference track reception 、 CTA negotiation 、 conflict warning sending 、 sending Landing request 、 departure track sending 、 meteorological information request.	Aircraft	Airborne Avionics Communication System
2	Human-computer interaction、Main flight display 、 Navigation display 、 EICAS display 、 NOTAMS display	Aircraft	Airborne Avionics Integrated Display Control System

No.	Information transferred and functions	Node	System
3	Data support, 、Confirm updated taxi path、Confirm launch permission 、 Confirm runway entry permit、Confirm landing permission 、 Process flight plan, 、 accept diversion track	Aircraft	Flight Management Computer System
4	Navigation data entry、navigation data processing	Aircraft	Flight Management Integrated Navigation System
5	Automatic flight control、Process track instructions	Aircraft	Flight Management Automatic Flight Control System
6	EPP data download	Aircraft	Flight Management Support Data System
7	Aircraft condition check	Aircraft	Flight Management Airborne Maintenance System
8	Power control	Aircraft	Airborne Power System
9	Sending of altitude change permission 、 bypass permission 、 and descent permission、 issue of conflict resolution instructions 、 sending of reference track updates、 sending of weather information、uploading of taxi routes	Area Control Center	Area Control Ground Communication System
10	EPP data download、flight monitoring 、 control handover 、 trajectory assessment result confirmation	Area Control Center	Area Control Ground Automation System
11	Reference trajectory update sending 、 weather information sending 、 approach permission sending 、 negotiation CTA,	Approach control center	Approach Control Ground Communication System、
12	Flight monitoring 、 control transfer、 and confirmation of trajectory assessment results	Approach control center	Approach Control Ground Automation System。

No.	Information transferred and functions	Node	System
13	Clearance permission sending 、 launch permission sending 、 landing permission sending, sending airspace status and usage restrictions 、 trajectory information sending 、 trajectory information receiving、 taxi path sending 、 negotiation CTA	Tower Control Center	Tower Control Ground Communication System
14	Taxi monitoring、track evaluation	Tower Control Center	Tower Control Ground Automation System
15	Send airspace status and usage restrictions, send route application approval	Air Route Traffic Control Center	Air Route Traffic Control Communication System
16	Feedback diversion track	Air Route Traffic Control Center	Air Route Traffic Control Automation System
17	Post initial diversion track	Airline	Airline Flight Operation Control Dispatch Operation Guarantee System
18	Send ideal flight track 、 send route request	Airline	Airline Flight Operation Control Communication Interface System
19	Feedback on track changes and submit to TBOT	Airline	Airline Flight Operation Control Integrated Information Management System
20	Confirm and store the updated departure trajectory, update, and confirm 、 share the ELDT time.	Air Traffic Flow Management Center	Air Traffic Flow Management Data Exchange And Service
21	Continuous monitoring and management of air traffic flow related issues	Air Traffic Flow Management Center	Air Traffic Flow Management Flight Flow Situation Display System
22	Predict and monitor the balance of capacity and flow in the terminal area 、 evaluate the trajectory	Air Traffic Flow Management Center	Air Traffic Flow Management Flight Flow Statistics Analysis System

No.	Information transferred and functions	Node	System
23	Post confirmed diverted trajectory, negotiate CTA、send update of planned trajectory、feedback trajectory evaluation results、send related flow management strategy	Air Traffic Flow Management Center	Air Traffic Flow Management Data Exchange And Service System
24	Upload weather and operation information, and publish NOTAMS.	Aviation Information Management	Aeronautical Information Dynamic Information System
25	Send weather information。	Weather Service Department	Meteorological Information Service System
26	Send the re-allocated runway information、send the allocated stand、release the updated stand、feedback the track evaluation result、confirm and store the updated departure track、and re-allocate the runway.	Airport	Airport Operation Management System

5.2. SYSTEM INTERFACE DESCRIPTION

System interface description considers how capability configuration, systems and organizations are established and crosslinked. It describes the system nodes and sub-system nodes required to fulfil operational activities, as well as the ports and interaction relationships among these nodes. It provides the connection of Operational View and System View, as the information exchange and input/output ports among sub-systems can be generated from operational node connectivity description. The sub-systems are identified as the physical entities of the abstract operational nodes in real scenario. The diagram of system interface description is shown in figure 24.

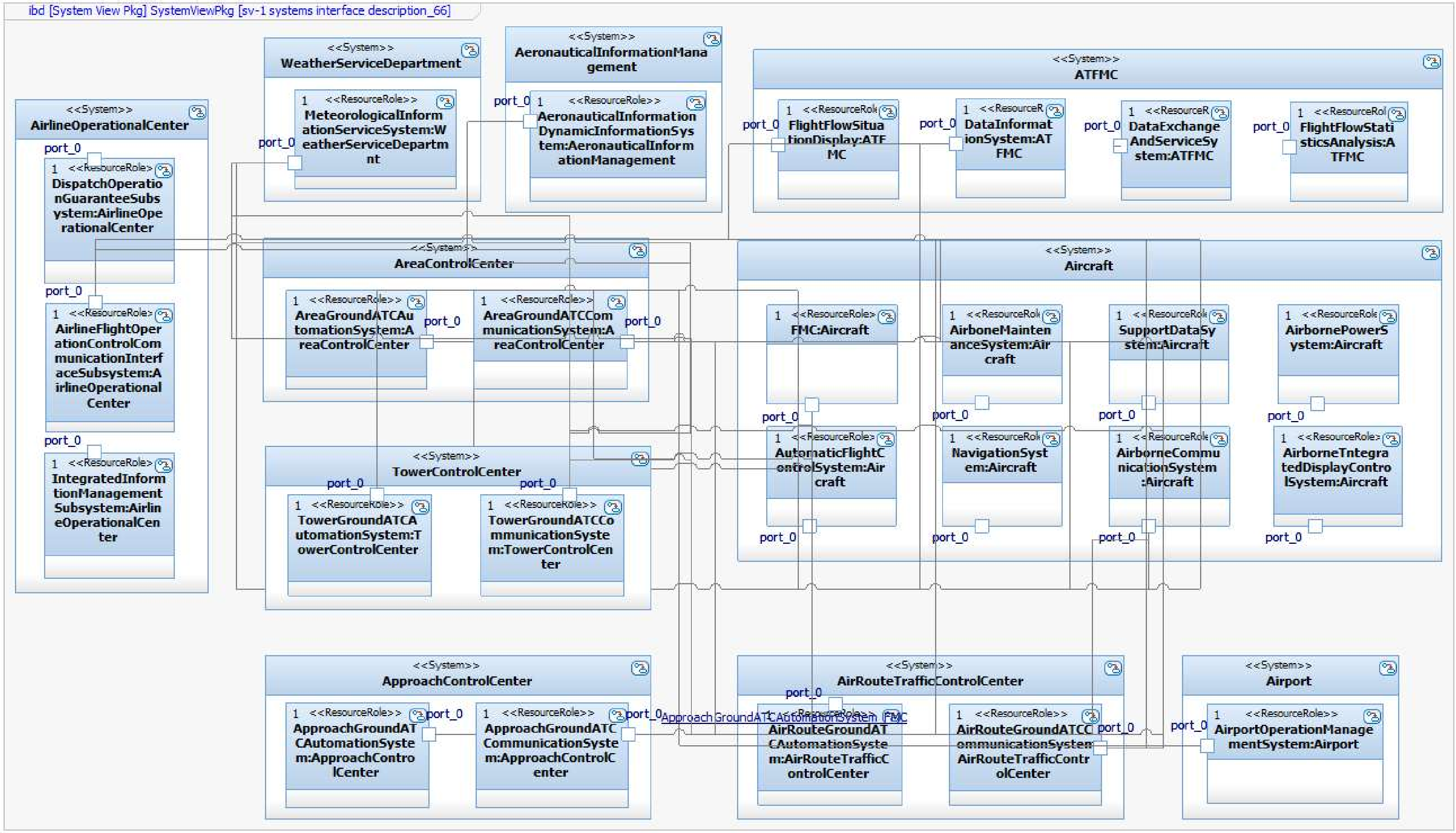

Figure 24. System Interface Description

5.2.1. PRE-DEPARTURE FLIGHT PLANNING

The flight planning phase relies on the cooperation of the aircraft, the tower control center, the air traffic control center, the Air Traffic Flow Management Center, the airlines, the intelligence department, the navigation department, and the airport in the node.

Required systems: Airborne avionics communication system, Airborne avionics integrated display control system, Flight management computer system, Flight management integrated navigation system, Flight management support data system, Flight management airborne maintenance system, Tower ground air traffic control communication system , Tower ground air traffic control automation system, Air route ground air traffic control communication system, Air route ground air traffic control automation system, Air traffic flow management data information system, Air traffic flow management flight flow statistics analysis system, Air traffic flow management data exchange and service system, Airline flight operation control dispatch operation guarantee system, Airline flight operation control communication interface system, Airline flight operation control integrated information management system, Meteorological information service system, Aeronautical information dynamic information system, Airport operation management system.

5.2.2. TAXI-OUT

The taxi-out phase relies on the cooperation of the aircraft, the tower control center, and the Air Traffic Flow Management Center.

Required systems: Airborne avionics communication system, Airborne avionics integrated display control system, Flight management computer system, Flight management integrated navigation system, Flight management support data system, Airborne power system, Tower ground air traffic control communication system, Tower Ground air traffic control automation system, Air traffic flow management data information system, Air traffic flow management flight flow situation display system, Air traffic flow management flight flow statistics analysis system.

5.2.3. DEPARTURE

The departure phase relies on the cooperation between the aircraft and the tower control center.

Required systems: Airborne avionics communication system, Airborne avionics integrated display control system, Flight management computer system, Flight management integrated navigation system, Flight management support data system, Airborne power system, Tower ground air traffic control communication system, Tower Ground air traffic control automation system.

5.2.4. CLIMBING

The climbing phase relies on the cooperation of the aircraft, the area control center, the approach control center, and the Air Traffic Flow Management Center.

Required systems: Airborne avionics communication system, Airborne avionics integrated display control system, Flight management computer system, Flight management integrated navigation system, Flight management support data system, Airborne power system, Regional ground air traffic control communication system, Area Ground air traffic control automation system, Approach control ground communication system, Approach control ground automation system, Air traffic flow management data information system, Air traffic flow management flight flow statistics analysis system, Air traffic flow management data exchange and service system.

5.2.5. CRUISING

The cruising phase relies on the cooperation of the aircraft, the regional control center, the Air Traffic Flow Management Center, the intelligence service department, and the airlines.

Required systems: Airborne avionics communication system, Airborne avionics integrated display control system, Flight management computer system, Flight management integrated navigation system, Flight management automatic flight control system, Flight management support data system, Airborne power system, Area control ground communication system, Area control ground automation system, Air traffic flow management data information system, Air traffic flow management flight flow statistics analysis system, Air traffic flow management data exchange and service system, Weather information service system, Airline flight operation Control dispatch operation guarantee system, Airline flight operation control communication interface system, Airline flight operation control integrated information management system.

5.2.6. DESCENT

The descent phase relies on the cooperation of the aircraft, area control center, approach control center, tower control center, Air Traffic Flow Management Center, intelligence service department, and airport.

Required systems: Airborne avionics communication system, Airborne avionics integrated display control system, Flight management computer system, Flight management integrated navigation system, Flight management support data system, Airborne power system, Regional ground air traffic control communication system, Area Ground air traffic control automation system, Approach control ground communication system, Approach control ground automation system, Tower ground air traffic control communication system, Tower ground air traffic control automation system, Air traffic flow management data information system, Air traffic flow management data exchange And service system, Weather information service system, Airport operation management system.

5.2.7. APPROACH

The approach phase relies on the cooperation of the aircraft, approach control center, and airport.

Required systems: Airborne avionics communication system, Airborne avionics integrated display control system, Flight management computer system, Flight management integrated navigation system, Flight management support data system, airborne power system, Approach control ground communication system, Approach control ground automation system, Airport operation management system.

5.2.8. LANDING

The landing phase relies on the cooperation of the aircraft and the tower control center.

Required systems: Airborne avionics communication system, Airborne avionics integrated display control system, Flight management computer system, Flight management integrated navigation system, Flight management support data system, Airborne power system, Tower ground air traffic control communication system, Tower Ground air traffic control automation system.

5.2.9. TAXI-IN

The taxi-in phase relies on the cooperation of the aircraft, tower control center, and airport.

Required systems: Airborne avionics communication system, Airborne avionics integrated display control system, Airborne power system, Tower ground air traffic control communication system, Tower ground air traffic control automation system, AirPort operation management system.

5.3. SYSTEM EVENT TRACE DESCRIPTION

System event trace description provides the state transition of clearly sequential graphical system functions as the participating unit in the whole mission objective, to describe how the system functions receive the impact of different events and change their own state. System event trace description is usually used together with system state transition description to describe the dynamics of system events, and provides a time-based check for the interaction between system functions, and provides a reasonable operation process for the realization of the whole mission objective.

5.3.1. PRE-DEPARTURE FLIGHT PLANNING

Table 13. System event trace description: pre-departure flight planning

Involved operational node	Involved system	State
Airline	Communication interface subsystem	Send route application
Air Route Traffic Control Center	Air Route Traffic Control system (communication)	Send airspace status and usage restrictions
Aviation Information Management	Meteorological Information Service System	Publish weather information
Airline	Airline Flight operation control system (dispatch operation guarantee subsystem)	Submit ideal flight path
ATFMC	Air traffic flow management system (data exchange and service)	Track evaluation and confirmation
	Air Traffic Flow Management System (Data Information System)	Send related traffic management strategies
Airline	Airline Flight operation control system （Communication interface subsystem）	Receive relevant traffic management strategies
	Airline Flight operation control system (dispatch operation guarantee subsystem)	Assess the impact of traffic management

Involved operational node	Involved system	State
ATFMC	Air Traffic Flow Management System (Data Information System)	Send planned track
Aviation Information Management	Meteorological Information Service System	Publish weather information
Airline	Airline Flight operation control system （Communication interface subsystem）	Submit TBOT
Tower Control Center	Tower Control Ground System (communication)	Taxi path allocation
	Tower Control Ground System (air traffic control automation system)	Upload departure track information
Aircraft	Airborne Avionics System (communication system)	Receive departure track information
	Flight management system (FMC)	Departure flight path calculation
Tower Control Center	Tower Control Ground System (communication)	Trajectory negotiation
	Tower Control Ground System (air traffic control automation system)	Send departure track
ATFMC	Air traffic flow management system (data exchange and service)	Feedback evaluation results
Airport	Airport Operation Management System	Feedback evaluation results
Area Control Center	Area Control Ground System (communication)	Feedback evaluation results
Approach control center	Approach Control Ground System (communication)	Feedback evaluation results
Tower Control Center	Tower Control Ground System (air traffic control automation system)	Upload track information
Aircraft	Airborne Avionics System (communication system)	Track information confirmation
Tower Control Center	Tower Control Ground System (communication)	Publish updated track

Involved operational node	Involved system	State
ATFMC	Air traffic flow management system (data exchange and service)	Receive and file
Airport	Airport Operation Management System	Receive and file
Area Control Center	Area Control Ground System (communication)	Receive and file
Approach control center	Approach Area Control Ground System (communication)	Receive and file

5.3.2. TAXI-OUT

Table 14. System event trace description: taxi-out

Involved operational node	Involved system	State
Aircraft	Flight Management System (Airborne Maintenance System)	Status check
Aircraft	Airborne Avionics System (communication system)	Send ATC clearance
Tower Control Center	Tower Control Ground System (communication)	Send ATC clearance application
Aircraft	Airborne Avionics System (communication system)	Send pushback clearance application
Tower Control Center	Tower Control Ground System (communication)	Send pushback clearance
Aircraft	Flight management system (automatic flight control system)	Execute taxi command
Tower Control Center	Tower Control Ground System (air traffic control automation system)	Monitor the consistency of the taxiing phase of the aircraft
ATFMC	Air Traffic Flow Management System (Flight Flow Statistics Analysis)	Forecast and monitor the balance of capacity and flow in the terminal area
Aircraft	Flight management system (FMC)	Conflict detection
	Airborne Avionics System (communication system)	Send conflict alert
Tower Control Center	Tower Control Ground System (air traffic control automation system)	Update taxi path

Involved operational node	Involved system	State
	Tower Control Ground System (communication)	Send taxi path
Aircraft	Flight management system (FMC)	Receive updated taxi path

5.3.3. DEPARTURE

Table 15. System event trace description: departure

Involved operational node	Involved system	State
Aircraft	Flight management system (FMC)	Execute taxi plan
Tower Control Center	Tower Control Ground System (communication)	Send runway clearance
Aircraft	Airborne Avionics System (communication system)	Confirm runway clearance
Aircraft	Airborne Avionics System (communication system)	Send pushback clearance application
Tower Control Center	Tower Control Ground System (communication)	Send pushback clearance
Aircraft	Flight management system (automatic flight control system)	Execute taxi command
Tower Control Center	Tower Control Ground System (air traffic control automation system)	Monitor the consistency of the taxiing phase of the aircraft
ATFMC	Air Traffic Flow Management System (Flight Flow Statistics Analysis)	Forecast and monitor the balance of capacity and flow in the terminal area
Aircraft	Flight management system (FMC)	Conflict detection
	Airborne Avionics System (communication system)	Send conflict alert
Tower Control Center	Tower Control Ground System (air traffic control automation system)	Update taxi path
	Tower Control Ground System (communication)	Send taxi path
Aircraft	Flight management system (FMC)	Receive updated taxi path

5.3.4. CLIMBING

Table 16. System event trace description: climbing

Involved operational node	Involved system	State
Approach control center	Approach Control Ground System (air traffic control automation system)	Monitor the climb phase of the aircraft
Aircraft	Flight management system (FMC)	Conflict detection
	Airborne Avionics System (communication system)	Send conflict alert
Approach control center	Approach Area Control Ground System (communication)	Send conflict resolution command
Aircraft	Flight management system (FMC)	Execute ATC command
Approach control center	Approach Control Ground System (air traffic control automation system)	Updated track
	Approach Area Control Ground System (communication)	Send updated track
Area Control Center	Area Control Ground System (air traffic control automation system)	Evaluation update and confirmation the track
ATFMC	Area Control Ground System (air traffic control automation system)	Area Control Ground System (air traffic control automation system)
Approach control center	Approach Control Ground System (air traffic control automation system)	Monitor aircraft operations
	Approach Area Control Ground System (communication)	Transfer of control
Area Control Center	Area Control Ground System (communication)	Confirm control transfer
Aircraft	Airborne Avionics System (communication system)	Confirm control transfer

5.3.5. CRUISING

Table 17. System event trace description: cruising

Involved operational node	Involved system	State
Area Control Center	Area Control Ground System (air traffic control automation system)	Monitor aircraft operations 过程
Aircraft	Flight management system (FLIGHT MANAGEMENT COMPUTER)	Identify changes in wind direction and speed
		Identify more fuel-efficient altitude layers
	Airborne Avionics System (communication system)	Apply to change altitude
Area Control Center	Area Control Ground System (air traffic control automation system)	Assess the airspace operation situation
	Area Control Ground System (communication)	Send change clearance
Aircraft	Airborne Avionics System (communication system)	Receive altitude change clearance
	Flight management system (automatic flight control system)	Complete maneuver flight
	Flight management system (FLIGHT MANAGEMENT COMPUTER)	Download the latest EPP data
Approach control center	Approach Control Ground System (air traffic control automation system)	Update track
	Approach Control Ground System (communication)	Send updated track
Area Control Center	Area Control Ground System (air traffic control automation system)	Evaluate、 update, and confirm the track
ATFMC	Area Control Ground System (air traffic control automation system)	Area Control Ground System (air traffic control automation system)
Approach control center	Approach Control Ground System (air traffic control automation system)	Monitor aircraft operations
	Area Control Ground System (communication)	Transfer the control
Area Control Center	Area Control Ground System (communication)	Confirm control transfer

Involved operational node	Involved system	State
Aircraft	Airborne Avionics System (communication system)	Confirm control transfer

5.3.6. DESCENT

Table 18. System event trace description: descent

Involved operational node	Involved system	State
Area Control Center	Area Control Ground System (air traffic control automation system)	Monitor aircraft operations
Aircraft	Airborne Avionics System (communication system)	Apply weather and operational information
Area Control Center	Area Control Ground System (air traffic control automation system)	Plan approach trajectory plan
	Area Control Ground System (communication)	Generate new approach track
Aviation Information Management	Meteorological Information Service System	Upload weather and operating information
Aircraft	Flight management system (FLIGHT MANAGEMENT COMPUTER)	Generate initial approach trajectory
	Approach Control Ground System (communication)	Download ETA window
Approach control center	Approach Control Ground System (communication)	Negotiate CTA
Tower Control Center	Tower Control Ground System (communication)	Negotiate CTA
ATFMC	Air Traffic Flow Management System (Data Information System)	Transfer of control
Aircraft	Flight management system (FLIGHT MANAGEMENT COMPUTER)	Confirm Update track
Area Control Center	Area Control Ground System (air traffic control automation system)	Confirm control transfer

Involved operational node	Involved system	State
ATFMC	Air Traffic Flow Management System (Data Information System)	Share ELDT time
Airport	Airport Operation Management System	Send assigned airport gate
Area Control Center	Area Control Ground System (air traffic control automation system)	Upload taxi path
Aircraft	Flight management system (FLIGHT MANAGEMENT COMPUTER)	Receive surface taxi information
Area Control Center	Area Control Ground System (communication)	Send descend clearance
Aircraft	Airborne Avionics System (communication system)	Confirm clearance
Area Control Center	Area Control Ground System (air traffic control automation system)	Monitor aircraft operations
Aircraft	Airborne Avionics System (communication system)	Execute ATC command
Area Control Center	Area Control Ground System (air traffic control automation system)	Update descend reference track
Aircraft	Airborne power system	Reached the control handover height
Approach control center	Approach Control Ground System (communication)	Confirm control transfer
Aircraft	Airborne Avionics System (communication system)	Confirm control transfer

5.3.7. APPROACH

Table 19. System event trace description: approach

Involved operational node	Involved system	State
Approach control center	Approach Control Ground System (air traffic control automation system)	Monitor aircraft operations
Aircraft	Flight management system (FLIGHT MANAGEMENT COMPUTER)	Evaluate CTA

Involved operational node	Involved system	State
	Airborne Avionics System (communication system)	Negotiate CTA
Aircraft	Flight management system (automatic flight control system)	Adjust the speed
Approach control center	Approach Control Ground System (communication)	Control aircraft sequence approach
	Approach Control Ground System (communication)	Send approach clearance
Approach control center	Flight management system (FLIGHT MANAGEMENT COMPUTER)	Authorize airborne interval maintenance
Aircraft	Flight management system (automatic flight control system)	Start the approach according to the airborne interval
Approach control center	Approach Control Ground System (air traffic control automation system)	Monitor aircraft operations
Airport	Airport Operation Management System	Post updated stands
Approach control center	Approach Control Ground System (air traffic control automation system)	Update the approach taxi path
	Approach Control Ground System (air traffic control automation system)	Upload updated taxi path
Aircraft	Airborne Avionics System (communication system)	Confirm updated taxi path
Approach control center	Approach Control Ground System (communication)	Announce the weather information of the runway
Airport	Airport Operation Management System	Send assigned stands
Aircraft	Flight management system (automatic flight control system)	Ready to land
Aircraft	Flight management system (FLIGHT MANAGEMENT COMPUTER)	Receive surface taxi information
Area Control Center	Area Control Ground System (communication)	Send descend clearance
Aircraft	Airborne Avionics System (communication system)	Confirm clearance

Involved operational node	Involved system	State
Area Control Center	Area Control Ground System (air traffic control automation system)	Monitor aircraft operations
Aircraft	Airborne Avionics System (communication system)	Execute ATC command
Area Control Center	Area Control Ground System (air traffic control automation system)	Update descend reference track
Aircraft	Airborne power system	Reached the control handover height
Approach control center	Approach Control Ground System (communication)	Confirm control transfer
Aircraft	Airborne Avionics System (communication system)	Confirm control transfer

5.3.8. LANDING

Table 20. System event trace description: landing

Involved operational node	Involved system	State
Tower Control Center	Tower Control Ground System (air traffic control automation system)	Monitor aircraft operations 过程
Airport	Airport Operation Management System	Post reassigned runway information
Aircraft	Flight management system (FLIGHT MANAGEMENT COMPUTER)	Receive updated runway information
	Airborne Avionics System (communication system)	Send landing clearance application
Tower Control Center	Tower Control Ground System (communication)	Send landing clearance
Aircraft	Airborne Avionics System (communication system)	Confirm landing clearance
	Flight management system (automatic flight control system)	Land

5.3.9. TAXI-IN

Table 21. System event trace description: taxi-in

Involved operational node	Involved system	State
Aircraft	Airborne power system	Slide off the runway
Tower Control Center	Tower Control Ground System (communication)	Send slide-in clearance
Aircraft	Airborne Avionics System (communication system)	Confirm slide-in clearance
Tower Control Center	Tower Control Ground System (air traffic control automation system)	Monitor aircraft operations
	Tower Control Ground System (communication)	Send Park clearance
Aircraft	Airborne Avionics System (communication system)	Confirm park clearance
	Airborne power system	Enter the stand

5.4. SYSTEM STATE TRANSTION DESCRIPTION

System State Transition Description provides a clear sequential graphical representation of system functions to describe how system functions respond to different events by changing their own state. The model basically represents a set of events that the resources in the activity respond to, as a transition process of the current state, and each state transition will be explained in detail the relationship between an event and a state. This description is similar to the operational state transition description, in which each state will be affected by different events, causing the next state to change. Therefore, when an event occurs, the next state to appear depends on the current state, the impact of the event and other conditions.

5.4.1. AIRBORNE AVIONICS SYSTEM (COMMUNICATION SYSTEM)

Table 22. System state transition description: Airborne Avionics System (Communication System)

Event	System state transition	System external response
Send ATC clearance application	Receive ATC clearance application	Send ATC clearance to Tower Control Ground System (communication)
Send ATC clearance	Receive ATC clearance	Send ATC clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send pushback clearance application	Receive pushback clearance application	Send pushback clearance application to Tower Control Ground System (communication)
Send pushback clearance	Receive pushback clearance	Send ATC clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send runway clearance	Receive runway clearance	Send runway clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send conflict alert	Receive conflict alert	Send conflict alert to Approach Control Ground System (communication)
Send conflict resolution command	Receive conflict resolution command	Send conflict resolution command to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send altitude change application	Receive altitude change application	Send altitude change application to Area Control Center Ground ATC system (communication)
Send Altitude change clearance	Receive Altitude change clearance	Send Altitude change clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send fly-around clearance application	Receive fly-around clearance application	Send fly-around clearance application to Area Control Center Ground ATC system (communication)

Event	System state transition	System external response
Send ATC clearance application	Receive ATC clearance application	Send ATC clearance to Tower Control Ground System (communication)
Send ATC clearance	Receive ATC clearance	Send ATC clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send pushback clearance application	Receive pushback clearance application	Send pushback clearance application to Tower Control Ground System (communication)
Send pushback clearance	Receive pushback clearance	Send ATC clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send runway clearance	Receive runway clearance	Send runway clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send conflict alert	Receive conflict alert	Send conflict alert to Approach Control Ground System (communication)
Send conflict resolution command	Receive conflict resolution command	Send conflict resolution command to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send altitude change application	Receive altitude change application	Send altitude change application to Area Control Center Ground ATC system (communication)
Send fly-around clearance	Receive fly-around clearance	Send fly-around clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send descend clearance	Receive descend clearance	Send descend clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send land clearance application	Receive land clearance application-	Send land clearance application to Tower Control Ground System (communication)

Event	System state transition	System external response
Send ATC clearance application	Receive ATC clearance application	Send ATC clearance to Tower Control Ground System (communication)
Send ATC clearance	Receive ATC clearance	Send ATC clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send pushback clearance application	Receive pushback clearance application	Send pushback clearance application to Tower Control Ground System (communication)
Send pushback clearance	Receive pushback clearance	Send ATC clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send runway clearance	Receive runway clearance	Send runway clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send conflict alert	Receive conflict alert	Send conflict alert to Approach Control Ground System (communication)
Send conflict resolution command	Receive conflict resolution command	Send conflict resolution command to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send altitude change application	Receive altitude change application	Send altitude change application to Area Control Center Ground ATC system (communication)
Send land clearance application	Receive land clearance application	Send land clearance application to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send slide-in clearance application	Receive slide-in clearance application	Send slide-in clearance application to Tower Control Ground System (communication)
Send slide-in clearance	Receive slide-in clearance	Send slide-in clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)

Event	System state transition	System external response
Send ATC clearance application	Receive ATC clearance application	Send ATC clearance to Tower Control Ground System (communication)
Send ATC clearance	Receive ATC clearance	Send ATC clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send pushback clearance application	Receive pushback clearance application	Send pushback clearance application to Tower Control Ground System (communication)
Send pushback clearance	Receive pushback clearance	Send ATC clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send runway clearance	Receive runway clearance	Send runway clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send conflict alert	Receive conflict alert	Send conflict alert to Approach Control Ground System (communication)
Send conflict resolution command	Receive conflict resolution command	Send conflict resolution command to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send altitude change application	Receive altitude change application	Send altitude change application to Area Control Center Ground ATC system (communication)
Send park clearance	Receive park clearance	Send park clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send airspace status and usage restrictions	Receive airspace status and usage restrictions	Send airspace status and usage restrictions to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send Runway information	Receive Runway information	Send Runway information to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)

Event	System state transition	System external response
Send ATC clearance application	Receive ATC clearance application	Send ATC clearance to Tower Control Ground System (communication)
Send ATC clearance	Receive ATC clearance	Send ATC clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send pushback clearance application	Receive pushback clearance application	Send pushback clearance application to Tower Control Ground System (communication)
Send pushback clearance	Receive pushback clearance	Send ATC clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send runway clearance	Receive runway clearance	Send runway clearance to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send conflict alert	Receive conflict alert	Send conflict alert to Approach Control Ground System (communication)
Send conflict resolution command	Receive conflict resolution command	Send conflict resolution command to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send altitude change application	Receive altitude change application	Send altitude change application to Area Control Center Ground ATC system (communication)
Upload weather information	Receive and save Weather information	Publish weather information to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
Send reassigned runway information	Receive Runway information	Send Runway information to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)

5.4.2. AIRBORNE AVIONICS SYSTEM (INTEGRATED DISPLAY CONTROL SYSTEM)

Table 23. System event trace description: Airborne Avionics System (Integrated Display Control System)

Event	System state transition	System external response
Null	Flight data monitoring	Send Flight data to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)

5.4.3. FLIGHT MANAGEMENT SYSTEM (FLIGHT MANAGEMENT COMPUTER)

Table 24. System event trace description: Flight Management System (Flight Management Computer)

Event	System state transition	System external response
The weather service department sends public weather report to the user (aircraft)	Receive 、backup and use	Null
Null	Generate ATC clearance	The aircraft send ATC clearance to the tower control center
Tower Control Center Send ATC clearance to aircraft	Receive and generate pushback clearance	The aircraft send pushback clearance to the Tower Control Center
Tower Control Center send pushback clearance to aircraft	Receive and generate runway application	The aircraft send runway application clearance to the tower control center
Tower Control Center send runway clearance to aircraft	Receive and generate Departure application	The aircraft send Departure application to the Tower Control Center
Detected conflict with other aircraft	Generate conflict alert	The aircraft send conflict alert clearance to the tower control center
Tower Control Center send updated track to aircraft	Receive and generate Departure application	The aircraft send Departure application to the Tower Control Center
Tower Control Center sends takeoff clearance to aircraft	Receive and generate Takeoff report	The aircraft send Takeoff report to the Air Traffic Services Report Office
Approach Control Center to aircraft send ascent command	Receive Send ascent command	Departure, cruise
Aircraft recognizes more fuel-efficient altitude	Send altitude change application	The aircraft sends an altitude change application to the Area Control Center
Area Control Center to aircraft Send Altitude change clearance	Receive altitude change command	Change to a more fuel-efficient altitude
Receive monitoring and control information	Update Information	Null
Area Control Center explains real-time weather information to aircraft	Receive and file	Null
Area Control Center update track to aircraft	Receive and update track	The aircraft cruises on the updated track
Area Control Center to aircraft upload weather and operating information	Receive 、file, and assess meteorological conflicts	Generate the initial changed track and send it to Airline;

Airline Send Updated track to Aircraft	Receive and Update track	The aircraft sends a fly-around clearance application to the Area Control Center
Area Control Center send fly-around clearance to aircraft	Calculate the track and generate EPP	Recalculate the track and download EPP
ATC share approach track with aircraft	Receive and file	Null
Aviation Information Management to aircraft Upload weather and operating information	Receive and file	The aircraft specifies the initial approach trajectory and downloads the ETA window
Area Control Center upload the negotiated CTA to the aircraft	Receive and file	Aircraft confirm and Update track
Area Control Center Send descend clearance to aircraft	Receive and Descend	Descend
Approach control center Authorize airborne interval maintenance to aircraft	Receive and keep interval	Approach
Prepare for approach	Generate Approach application	Send Approach application
Ready to land	Generate land application	Send land application
Landed	Generate land report	Send land report
Landed	land and generate Service facility service report	The aircraft sends a flight report to Tower Control Center, Approach Control Center, and Area Control Center

5.4.4. FLIGHT MANAGEMENT SYSTEM (INTEGRATED NAVIGATION SYSTEM)

Table 25. System event trace description: Flight Management System (Integrated Navigation System)

Event	System state transition	System external response
Null	Guide the heading and correct the error during the flight	Null
Null	Heading monitoring	Send heading monitoring to Flight management system (FLIGHT MANAGEMENT COMPUTER)

Send updated track	Receive and update track	Send updated track to Flight management system (FLIGHT MANAGEMENT COMPUTER)

5.4.5. FLIGHT MANAGEMENT SYSTEM (AUTOMATIC FLIGHT CONTROL SYSTEM)

Table 26. System event trace description: Flight management system (Automatic Flight Control System)

Event	System state transition	System external response
Receive aircraft control information	Maneuver the aircraft vertically, horizontally, and longitudinally to make the aircraft fly normally	Null
Receive aircraft control information	Keep current course	Null
Receive aircraft control information	Follow the instructions of the flight service station to fly	Null

5.4.6. FLIGHT MANAGEMENT SYSTEM (SUPPORT DATA SYSTEM)

Table 27. System event trace description: Flight Management System (Support Data System)

Event	System state transition	System external response
Null	Provide performance data support	Send Performance database to Flight management system (FLIGHT MANAGEMENT COMPUTER)

5.4.7. FLIGHT MANAGEMENT SYSTEM (AIRBORNE MAINTENANCE SYSTEM)

Table 28. System event trace description: Flight Management System (Airborne Maintenance System)

Event	System state transition	System external response
Null	The aircraft constantly checks its own status, Generate aircraft status report	The aircraft sends aircraft status reports to Tower Control Center and Airline

5.4.8. AIRBORNE POWER SYSTEM

Table 29. System event trace description: Airborne Power System

Event	System state transition	System external response
Null	Provide power support	Null

5.4.9. AREA CONTROL GROUND SYSTEM (COMMUNICATION)

Table 30. System event trace description: Area Control Ground System (Communication)

Event	System state transition	System external response
Receive Altitude change clearance application	Receive Altitude change clearance application	Send Altitude change clearance
Receive fly-around clearance application	Receive fly-around clearance application	Send fly-around clearance
Aircraft arrives at TOD	Receive descend clearance application	Send descend clearance
Send conflict resolution command	Send conflict resolution command	File

5.4.10. AREA CONTROL GROUND SYSTEM (AIR TRAFFIC CONTROL AUTOMATION SYSTEM)

Table 31. System event trace description: Area Control Ground System (Air Traffic Control Automation System)

Event	System state transition	System external response
Aircraft download EPP	Receive EPP	Null
Send Monitoring information request	Receive Monitoring information request	Monitor aircraft operations
Publish weather information	Receive fly-around clearance application	Send fly-around clearance
Aircraft send fly-around clearance application	Receive and calculate reference track	Send reference track
Approach Control Center 、Tower Control Center 、 ATFMC and Area Control Center Negotiate CTA	Generate CTA	Upload the negotiated CTA to the Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)
ATC glide path planning through SMAN	Taxi path planning	Send taxi path to Airborne Avionics System (FLIGHT MANAGEMENT COMPUTER)

5.4.11. APPROACH CONTROL GROUND SYSTEM (COMMUNICATION)

Table 32. System event trace description: Approach Control Ground System (Communication)

Event	System state transition	System external response
Aircraft Evaluate CTA	Determine CTA status	Negotiate CTA
Aircraft confirm updated taxi path to Approach control center	Taxi path confirmation	File
Publish weather information	Receive Weather information	File

5.4.12. APPROACH CONTROL GROUND SYSTEM (AIR TRAFFIC CONTROL AUTOMATION SYSTEM)

Table 33. System event trace description: Approach Control Ground System (Air Traffic Control Automation System)

Event	System state transition	System external response
Monitor aircraft operations	Generate Real-time monitoring information	Send Real-time monitoring information
Receive flight situation report	File	Null
Receive approach clearance	Generate approach clearance	Send approach clearance
Receive departure application	Generate Send ascent command	Send ascent command
Receive Flight traffic information	Coordinate approach and departure	Coordinate approach and departure
Generate Navigation status information	Receive Navigation status information	File

5.4.13. TOWER CONTROL GROUND SYSTEM (COMMUNICATION)

Table 34. System event trace description: Tower Control Ground System (Communication)

Event	System state transition	System external response
Send ATC clearance	Receive ATC clearance	Verify mission
Generate ATC clearance	Send ATC clearance	Send ATC clearance
Send Taxi application	Receive Taxi application	Generate Taxi clearance
Generate Taxi clearance	Send Taxi clearance	Send Taxi clearance

Send runway clearance application	Receive runway clearance application	Generate Approval information
Send land clearance application	Receive and clearance application	Generate Approve landing information
Generate Approve landing information	Send Approve landing information	Send Approve landing information
Send Taxi application	Receive Taxi application	Generate Taxi clearance
Generate Taxi clearance	Send Taxi clearance	Send Taxi clearance
Send NOTAMS	Receive NOTAMS	Receive and file
Submit TBOT	Confirm TBOT	Send TBOT
Send Stand information	Receive Stand information	Confirm parking bay information with the aircraft

5.4.14. TOWER CONTROL GROUND SYSTEM (AIR TRAFFIC CONTROL AUTOMATION SYSTEM)

Table 35. System event trace description: Tower Control Ground System (Air Traffic Control Automation System)

Event	System state transition	System external response
Receive airspace planning scheme	save airspace planning scheme	Develop take-off and landing plans
Receive Track change request	Trajectory assessment	Negotiate track
Receive ATC clearance	Verify mission	Generate ATC clearance
Receive runway clearance application	Generate Approval information	Send Approval
Receive and Approved to take off	Approved to take off	Send take-off permission
Monitor aircraft operation	Generate Real-time monitoring information	Send Real-time monitoring information

5.4.15. AIR ROUTE TRAFFIC CONTROL GROUND SYSTEM (COMMUNICATION)

Table 36. System event trace description: Air Route Traffic Control Ground System (Communication)

Event	System state transition	System external response
Send route request application	Receive route request application	Send Approval
Send Aircraft flight status report	Receive Aircraft flight status report	Store navigational status

Monitor aircraft operation	Aircraft found a state of emergency	Store monitoring data
Null	Real-time monitoring and area control	Generate Monitoring and control information
Receive Flight flow information	Negotiate route change	File
Forward pilot weather report	Receive pilot weather report	File
Send Monitoring information request	Receive Monitoring information request	Monitor aircraft operation
Send flight situation report	Receive flight situation report	File

5.4.16. AIR ROUTE TRAFFIC CONTROL GROUND SYSTEM (AIR TRAFFIC CONTROL AUTOMATION SYSTEM)

Table 37. System event trace description: Air Route Traffic Control Ground System (Air Traffic Control Automation System)

Event	System state transition	System external response
Generate Airspace information	Analysis and planning	Generate Airspace planning scheme
Generate Approval information	Receive Approval information	save and planning route
Application Did not pass	Re-application	Generate new route usage application

5.4.17. AIRLINE OPERATIONAL CONTROL SYSTEM (DISPATCH OPERATION GUARANTEE SUBSYSTEM)

Table 38. System event trace description: Airline Operational Control System (Dispatch Operation Guarantee Subsystem)

Event	System state transition	System external response
Send flight Plan	Receive flight plan	Confirm flight plan
Send confirmed new track	Receive confirmed new track	File

5.4.18. AIRLINE OPERATIONAL CONTROL SYSTEM (COMMUNICATION INTERFACE SUBSYSTEM)

Table 39. System event trace description: Airline Operational Control System (Communication Interface Subsystem)

Event	System state transition	System external response
Send flight plan	Receive flight plan	Confirm flight plan
Send confirmed new track	Receive confirmed new track	File
Send route application approval	Receive route application approval	File
Send airspace status and usage restrictions	Receive airspace status and usage restrictions	File
Send related traffic management strategies	Receive relevant traffic management strategies	File
Publish weather information	Receive weather information	File

5.4.19. AIRLINE OPERATIONAL CONTROL SYSTEM (DATA INFORMATION SYSTEM)

Table 40. System event trace description: Airline Operational Control System (Data Information System)

Event	System state transition	System external response
Send reference track	Update reference track	File
Trajectory assessment	Generate Update track	Send updated track
Post initial changed track	Receive initial changed track	Receive and file
Confirm and store updated track	Receive updated track	Receive and file

5.4.20. AIR TRAFFIC FLOW MANAGEMENT SYSTEM (FLIGHT FLOW SITUATION DISPLAY)

Table 41. System event trace description: Air Traffic Flow Management System (Flight Flow Situation Display)

Event	System state transition	System external response
Send Monitoring request	Receive Monitoring request	Monitor flow related issues

5.4.21. AIR TRAFFIC FLOW MANAGEMENT SYSTEM (FLIGHT FLOW STATISTICS ANALYSIS)

Table 42. System event trace description: Air Traffic Flow Management System (Flight Flow Statistics Analysis)

Event	System state transition	System external response
Send Monitoring request	Receive Monitoring request	Monitor the current capacity of the terminal area

5.4.22. AIR TRAFFIC FLOW MANAGEMENT SYSTEM (DATA EXCHANGE AND SERVICE)

Table 43. System event trace description: Air Traffic Flow Management System (Data Exchange And Service)

Event	System state transition	System external response
Confirm, update, and evaluate track	Receive and save updated track	Receive and file

5.4.23. AERONAUTICAL INFORMATION DYNAMIC INFORMATION SYSTEM

Table 44. System event trace description: Aeronautical Information Dynamic Information System

Event	System state transition	System external response
Send airspace status and usage restrictions	Receive airspace status and usage restrictions	Receive and file
Send Ideal flight track	Receive Ideal flight track	Receive and file

5.4.24. METEOROLOGICAL INFORMATION SERVICE SYSTEM

Table 45. System event trace description: Meteorological Information Service System

Event	System state transition	System external response
Weather information request	Confirm Weather information request	Publish weather information

6. CONCLUSION AND OUTLOOK

By capturing and analyzing the system requirements, the modeling of greener air traffic operation system architecture based on four-dimensional trajectory operations is completed. The ATM system supporting greener air traffic operation is a multi-agent and multi-node complex system. In order to cope with the complexity, MBSE method is used to analyze its operational and system architecture. The MBSE-based system architecture design approach provides a clear OV and SV view of the ATM architecture framework, and describes the 4DT-based greener air traffic operation process in multiple dimensions. Through the establishment of architecture models and functionality models, ATM system development requirements under greener air traffic operational concept can be effectively obtained. Compared with the document-based system engineering approach, the model-based system engineering approach has advantages mainly in the aspects like non-ambiguity of knowledge representation, improved efficiency of communication, integration of system design, reusability of system content and enhanced knowledge acquisition and reuse, which makes it a useful and effective methodology in ATM architecture development.

This research helps to better utilize the four-dimensional trajectory in the future green air traffic operation system to improve the flight operation efficiency, environmental friendliness, and safety. By establishing architecture from operational view to system view, it can be considered as a feasible approach to build a bridge from operational concepts to technology development and implementation. In future research, the scenarios can be further refined and demonstrated and used in validation for specific airspace or other typical scenarios.

In the future researches, when further refining these scenarios, some lessons learnt in Europe might be taken into consideration. In certain cases, due to high traffic in relatively small geographic areas, the full application of Free Route Airspace suffers from certain limitations. On the one hand, national RADs must be extended in order to suffice traffic demand. On the other hand, vertical limitations (level capping) may be introduced, which means that in the most congested areas, between city-pairs of relatively short distances, flights cannot or do not climb into ACC sectors, but they are controlled by APP services. The level constrains between the ATS units also might distort the ideal profiles. This is a relatively big proportion of flights in the so-called ‘Core area’ in Europe.

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