Operational Scenario Analysis Method for Civil Aircraft Based on Requirement Capture

He Yuwei\(^a\)*, Sun Yuchen\(^b\), Zhang Xinai\(^c\), Dai Ximei\(^d\) and Chen Dongsheng\(^e\)

Requirements Engineering Department, Shanghai Aircraft Design and Research Institute, Shanghai, China

\(^a\) heyuwei@comac.cc; \(^b\) sunyuchen@comac.cc; \(^c\) zhangxinai@comac.cc; 
\(^d\) daiximei@comac.cc; \(^e\) chendongsheng@comac.cc

Abstract: Scenario analysis is an accepted method in civil aircraft requirements capture and validation. This paper introduces the operation scenario analysis method for requirement capture, including stakeholder identification, interaction activity analysis, design requirement capture, etc. Based on SysML language, the modeling and analysis of operation scenarios were carried out. Taking the push/tow scenario of civil aircraft as an example, the structure diagram, use case diagram, activity diagram and requirement diagram are formed by modeling. The design requirements in this scenario are captured through the interaction analysis between the different stakeholders and the aircraft.

Keywords: Civil aircraft, System engineering, operational scenario, Requirement capture.

1. Introduction

As mentioned in SAE ARP 4754 and INCOSE[1], one of the difficulties in ensuring requirements integrity is that users do not always know what they do or do not want to do in the system, especially for new or novel features. There are many ways to get requirements from users. Early capture and prototyping of operational and maintenance scenarios is an example of how to capture requirements. It can be seen that scenario analysis is an accepted technical method in civil aircraft requirement acquisition and validation.

What kind of situation the aircraft will encounter in the whole operation process is the operational scenario of the aircraft, including the combination of various states and environments of the aircraft in the whole operation process. As the starting point and basic basis of aircraft design, the perfection of scenario definition is closely related to the correctness and completeness of top-level requirements, and also has a certain impact on safety analysis, test verification, airworthiness forensics and other work. If we can consider all the scenarios that the aircraft may encounter in the whole operation process at the beginning of aircraft design, it will save the development cost of the aircraft manufacturer and improve the efficiency of the aircraft after it is put into operation.

At the very beginning of aircraft development, the needs of stakeholders for aircraft products need to be determined. In addition, due to the long development cycle of aircraft products, the acquisition of requirements at the beginning of design also depends on the new operation and use requirements in the future. It is important to ensure that these requirements will apply in the future even if external conditions change, but uncertainty about the future makes it difficult to predict how future customer demand will develop[2].
One option to deal with future uncertainty is through scenario planning, which "represents the range of possible future developments" by creating multiple equally realistic descriptions of the future (scenarios). Scenarios capture future uncertainty in this way by considering a wide range of potential futures, and thus can form the basis for initiating robust design requirements. In this sense, scenarios, unlike prediction or trend extrapolation, do not represent natural states or predictions, but stipulate that systems that might operate in the future world must be reviewed. In fact, "scenario planning" has been used by aerospace companies for decades as a way to deal with future uncertainty.

The aircraft operational scenario is to put the expected aircraft in the entire air transport System at the very beginning of aircraft development and study the interaction between the aircraft and the System of System, such as the interaction between the aircraft and air traffic control, tower and other ground equipment. On the other hand, based on the concept of customer-oriented aircraft design, it is necessary to analyze the interaction between aircraft and external stakeholders and operating environment from the perspective of stakeholders using aircraft, which is operational scenario analysis.

2. Aircraft operational scenario
The original intention of Scenario, is derived from the drama, which refers to the gist of the plot. The general explanation can be understood as: a combination of events with certain relations. As a technology of requirements capture, scenario analysis refers to the method of obtaining requirements by placing the product to be developed in the scenario of its operation and analyzing its expected activity in the scenario. Scenario analysis is a creative way of thinking that reduces the likelihood that important requirements in the system will be ignored, while the activity of developing scenarios promotes communication within the organization[3].

Scenario is a concept originated from software engineering. Designers often use scenario to model the user of software system and the series of interactive activities between the system and the user. In activities such as early requirement extraction, it is easier for Stakeholders to use concrete examples than abstract intentions when communicating requirements. A scenario can act as a middle layer between an abstract conceptual layer and a concrete reality, and it can act as a means of putting requirements into context and articulating requirements clearly. With the help of scenarios, stakeholders can communicate their requirements through a series of specific, exemplary interactions.

In recent years, the application of scenario concept has drawn more and more attention from demand engineering, software engineering and other fields. People define different concepts of scenarios when they use them in different ways. A scenario is "an interactive activity that is likely to occur between multiple objects, and the activity has a goal". This interactive activity is a sequence of activities that takes place between objects. The sequence of activities describes a path where a goal is met or not met. The scenario contains the start and end states. A scenario can also refer to a specific example in a use case that represents a specific process in a use case in detail. Scenarios can also be combined with a variety of methods, such as viewpoints, cognitive science, etc.

In the design process of civil aircraft, operational scenario refers to a series of interactive activities and physical connections with temporal and logical relationships between aircraft and external environment (including relevant stakeholders, various external systems and external environment) for performing a certain task from the perspective of users using aircraft.

The operational scenario must be able to cover all stages of the flight, including takeoff, climb, cruise, descent, approach, and landing. The flight scenario must be able to cover significant flight environments, including flight planning, crew missions, Air traffic management (ATC), air traffic approval and Routing. The flight scenario must be able to cover typical flight weather, including visibility, turbulence, ice accumulation, thunderstorms, wind shear, crosswinds, etc. The flight scenario must be able to cover a variety of aircraft factors, including weight, balance, minimum equipment list, failures, abnormal events, etc. The flight scenario must be able to cover the necessary flight operations related to the crew mission. The flight scenario must reflect all fundamental functions and factors related to flight operations (CCAR 25.1523 Appendix D). The flight scenario must be able to reflect the aviation stakeholder factors that affect the flight safety to some extent.
Operational scenario analysis technology is used to describe the interaction between the aircraft and the operating environment, and can be used to identify aircraft functions and capture requirements. The developed aircraft can be placed in future operational scenarios, and the requirements can be captured by analyzing the expected activity of the aircraft in the scenario[4].

3. Operational scenario analysis method

a) Operational scenario analysis process

In the conceptual design phase of aircraft development, it is necessary to carry out the operational scenario identification and definition activities, and capture the complete design requirements through a comprehensive analysis of the scenario. For the identified operational scenario, the design requirements can be captured by analyzing the operational scenario.

Analysis methods for operational scenarios mainly include stakeholder identification, interaction analysis between aircraft products and stakeholders, requirement capture, etc., as follows:

- Stakeholder identification: in a certain scenario node, the personnel involved in aircraft operation include the stakeholders directly in contact with the aircraft, such as pilots, flight attendants, passengers, etc., and also include the stakeholders indirectly in contact with the aircraft, such as air traffic control personnel, dispatchers, etc.;
- Interaction activity analysis: In order to complete specific tasks, stakeholders need to carry out a series of interaction actions with the aircraft (including the transfer of resources, information, data, etc.), which are the operational behaviors of stakeholders. The description of the operation activity of the stakeholders should be in the language format of "verb/preposition + name", such as piloting the aircraft. In the process of describing the operation behavior, specify the external operation limitation/constraint in the activity description as required;
- Design requirements capture: Based on the above analysis, the requirements based on this scenario are captured. The captured requirements should be recombined or generalized according to category similarity.

b) Operational scenario modeling and analysis

Scenario concepts have been introduced into the field of engineering design to communicate design requirements. In a systematic design approach, the requirement list information can be refined and extended by creating scenarios during the task elaboration phase. A scenario describes the activities of a product (or system) and its participants in a narrative manner, including a series of interactions between users and the product (or system), such as which participants are likely to use the product, how to use it, when and where to use it, and the reaction of the product during use, etc. Essentially, a scenario usually tells of a series of operations imposed by stakeholders on a product (or system) and the events and actions (real or virtual) that the product (or system) responds to. In general, a scenario usually defines at least one set of stakeholder activities and at least one set of product (or system) actions. Much of this comes from stakeholder experience. Therefore, when using scenarios to express requirements, the description of specific instances makes it more convenient for stakeholders and designers to communicate requirements. In addition, scenarios can also be used by designers to model the interactions between products and their work environment.

A complete scenario should at least explicitly include the following characteristics: actors, time, place, actions/events, and scenario conditions (including preconditions and postconditions).

The "actor" is the person or other product or system that interacts with the product (or system) and is the subject of the action or event. It is important to note that scenarios describe not only the interactions between the product (or system) and the actors, but also the interactions between the actors or between the actors and the environment. In addition, actors often have different roles in a scenario, and roles indicate a specific type of actor. The terms "time" and "place" indicate when and where the scenario occurred, and are background elements that characterize the context of a general scenario. "Action/event" refers to an event in which an actor has an effect or occurs on a product (or system). Certain actions of one actor or product can cause changes in the state of others. Before and after the
execution of the scenario, the state of each participant before and after constitutes the basic elements of the scenario conditions. Some conditions that must be met before the execution of the scenario (i.e., "pre-conditions") and those that should be met after the execution of a scenario (i.e., "post-conditions") are collectively referred to as "scenario conditions". It should be noted that the above several characteristic elements may not be included in every scenario. When one or more elements are omitted and the description and understanding of the scenario is not affected, it can be omitted.

Operational scenarios are widely used to ensure that the system (or set of systems) performs task requirements successfully. A operational scenario is a description of how the system should operate and interact with other systems. The scenario is described in a way that is easy to understand so that engineers can see how the various parts of the system work and interact, and verify that the system meets the needs and expectations of the user.

Describe a operational scenario that should target all operational patterns, task phases, and the sequence of critical activities for all users identified. Each scenario should appropriately include events, actions, information, and interactions to provide a full operational understanding of the system.

There are three main forms of scenario representation: natural language formal representation, formal language formal representation and semi-formal language formal representation. All three of the most simple and natural form is by people known as natural language, in the form of a "story" analysis to observe people's task, the description method for all stakeholders are usually easy to understand, but natural language form is easy to produce ambiguity causes the description form in the real use fuzzy demand may be produced. Another way is to use formal languages such as CSS, CSP, Z to describe the scenario. This method requires relevant personnel to have high professional knowledge and technology, which is difficult for users without professional knowledge and technology to understand and master. Therefore, it will be very difficult to communicate with users to capture requirements. The third and semi-formal form of description is the graphical form, which is well observed, simple, and useful for users to understand, so this approach is better than the previous two for users and developers to understand.

In the field of aviation, scenarios can be divided into the following three expressions: diagram, table and model.

Modeling analysis of operational scenarios based on SysML[5] language. SysML(System Modeling Language) is a new Modeling Language proposed by INCOSE[1] (International Council on Systems Engineering) and OBJECT management organization OMG based on the reuse and extension of a subset of UML, and it is adopted as the standard Modeling Language for Systems Engineering.

SysML has a total of 9 graphics, including the following contents:
- Module definition: Said of elements such as modules and value type and the relationships between those elements, usually display system hierarchy tree as well as the classification tree;
- Internal module: used to specify the internal structure of a single module, display module, the relationship between the internal part and the interface connections between them;
- Use-case diagrams: Show the system of the interaction between the user and the system, the system is under the coordination of actors performing service by the black box view;
- Activity diagram: specify a behavior, mainly focus on control process, output and input through a series of moves into a process;
- Sequence diagram: How is part of the display module to interact through calls and asynchronous operation signal, state the action occurred over time and sequence of events;
- State machine diagram: Show a series of based on state of the system module, and respond to events, the possibility of conversion between state;
- Graph: Parameters said in one or more constraints (especially the equality and inequality) and how the property of the system bound, namely the constraint relation between modules;
- Package diagram: A model to show package contains the hierarchy of each organization;
- Demand figure: It means the relationship between the demand and the demand based on text, and meet, validation, and improve their other model elements.
• Combined with the above SysML model definition and characteristics, the operational scenario can be defined by use case diagram model and refined by establishing sequence diagram and activity diagram models.

During the modeling and analysis of operational scenarios, the structure diagram, use case diagram, activity diagram and requirement diagram of stakeholders should be established respectively.

• Structure diagram: Stakeholders in a operational scenario, which can be represented as SysML structure diagram. Should with the flow of information/data link (such as navigation, communication, etc.), resource flow/solid interface (fuel, gas interface, etc.), stakeholder-aircraft interaction (units and aircraft maintenance and aircraft, etc.), environment influence on aircraft such as the main line for reference, all to identify the stakeholders involved in the scenario, such as tower, air traffic control, satellite and radar, etc.;

• Use case diagram: Based on the above information identification system boundary (inside the boundary is the aircraft system, outside the boundary is the environment and stakeholders), use case diagram to simply describe the interface relationship between the aircraft product and external stakeholders; Stakeholder use case diagram model, as shown in Figure 1;

• Activity analysis: During the model expression of Activity analysis diagram, independent swim lanes should be set up for the aircraft and stakeholders (such as pilots, flight attendants, passengers, air traffic controllers, dispatchers, air traffic service system, navigation system, communication system, etc.), which should be expressed in the form of flow chart. Using the line to express the sequential workflow and interaction relationship; At the same time, the key indicators/parameter variables/decision points that affect the performance of the scenario are considered to set logic/trigger instructions, as well as operation restrictions/constraints. The model diagram of the activity diagram is shown in figure 2.

• Demand diagram: Design requirements can be captured and represented by demand diagram through stakeholder-aircraft interaction analysis under a certain operational scenario combined with model development experience, etc.

![Figure 1. stakeholder use case diagram model diagram](image1)

![Figure 2. Activity analysis diagram model diagram](image2)
4. Operational scenario analysis example

This section describes an operational scenario analysis of a civilian aircraft for requirements capture, using aircraft push/tow as an example.

The aircraft push/tow scenario is a common operational scenario. This scenario mainly refers to the stage when the aircraft is in normal environment and normal operation in general operation, and when it is in normal environment and normal operation in general operation, the aircraft does not rely on its own power and USES ground equipment such as trailers to move in the airport activity area such as the corridor bridge, apron or parking space.

The stakeholders involved in this scenario include ground crew commander, tractor driver, service, maintenance, flight crew, air traffic control personnel (ATC), and flight attendants.

The main stakeholder-computer interaction activities include:

- a) Ground crew commander: Prepare for picking up the aircraft, direct the tractor to pre-position, direct the tractor to approach the aircraft at low speed, confirm that the tractor is connected to the aircraft, withdraw from the wheel gear, issue instructions for releasing the brakes, and direct the aircraft to push out/direct the tractor to pull out;
- b) Tractor driver: Pilot braking, confirm braking status, establish interphone, approach to the aircraft, put down and open the traction bracket, tow the aircraft/push the aircraft out;
- c) Service: Connect the tow bar to the aircraft, confirm that the brake is released, the wheel block is removed, and the front wheel turns and contacts the lock;
- d) Maintenance: Check the boarding bridge, evacuate the ground equipment, check the balance of fuel tank, check the compression amount of brake pressure damping pillar, and install the ground safety pin; Close the hatch cover, confirm the external lighting is normal, connect the internal communication;
- e) Flight crew: Apply for push/tow, set up external lighting, inform maintenance, prepare push/tow;
- f) ATC: Push/tow allowed;
- g) Steward: Direct passengers to board, close the gate.

The main stakeholder-aircraft interaction activities are shown in figure 5. According to the above stakeholder-aircraft interaction analysis, the aircraft should have the functions of providing external lighting, providing interphone, connecting with the tractor, wheel gear removal, brake release, front wheel turn contact locking, being pulled/pushed to the specified position and so on.

a) Modeling analysis

Based on SysML language, we use Magic Draw software to conduct the push/tow scenario analysis. Structure diagram is shown in figure 3, use case diagram is shown in figure 4 and scenario activity diagram is shown in figure 5.

![Figure 3. Stakeholder structure diagram](image-url)
b) Push/tow scenario design requirements capture

The main stakeholder-aircraft interaction activity in push/tow scenario is shown in figure 5. Based on the stakeholder-aircraft interaction analysis of the above aircraft push/tow scenario, the following design requirements are preliminarily captured:

- Aircraft shall provide sufficient means of internal and external communication;

![Use case diagram](image1)

**Figure 4. Use case diagram**

![Activity diagram](image2)

**Figure 5. Activity diagram**
• The aircraft lighting system shall provide external lighting to ensure the safety of the aircraft during takeoff, landing and navigation.
• The aircraft should have an interphone system to support real-time communication between the cockpit and ground service personnel;
• During aircraft installation and maintenance, the nose landing gear and cabin door shall be locked with safety pins;
• The cockpit of a civil aircraft shall provide sufficient field of view for the crew to observe conditions on the ground outside the aircraft;
• Under the maximum allowable towing weight of the aircraft, the civil aircraft shall be towed or propelled by a towed connected to the nose landing gear strut, and the nose landing gear shall have a joint connected to the towing accessories through which the aircraft shall be towed;
• The aircraft shall have braking function.

Acknowledgment
In the early stage of civil aircraft development, it is necessary to carry out aircraft operational scenario research. Through comprehensive scenario analysis, complete design requirements are captured, which is of great significance to improve the development level of new aircraft in China, improve aircraft design efficiency, and improve aircraft operation efficiency. In this paper, the operational scenario analysis method for civil aircraft based on requirements acquisition is proposed. Through the operational scenario analysis, the design requirements under this scenario are captured, which provides a feasible method for design requirements acquisition.

References
[1] International Association of Systems Engineering, INCOSE. Systems Engineering Manual [M]. Zhang Xinguo, trans. Beijing: Machinery Industry Press, 2014.
[2] A Guidelines for Development of Civil Aircraft and System [S]. The Engineering Society for Advancing Mobility Land Sea Air and Space, 2010. 5.
[3] Xie Ling, Fang Junwei, Xuzhou, et al. Research on aircraft requirements acquisition and confirmation Based on functional scenario analysis [J]. 2015,13 (18): 83-84;
[4] Deng xingmin, zhang huiyuan, li jianren, Yang chao. Application of requirement capture method based on operational scenario in turret [J]. Journal of northwest university of technology, 2017, 35(S1):88-92.
[5] Ni Zhongjian, Zhang Yan, et al. Application research of SysML system Design method [J]. Avionics technology, 2011,42 (1):18-23.