Using Model Based Systems Engineering to Create a Triple Channel Cognitive Concept of Operations

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Abstract **− The Concept of Operations describes how the system will satisfy the stakeholder's needs and how it will be operated after its development. This paper proposes the addition of a third cognitive layer to the two most used in the creation of the ConOps. The current method of creating ConOps is studied, followed by the presentation of the methodology used for the development of the triple channel ConOps. A widely known case study is used to apply the methodology then, is possible to analyze the benefits and difficulties of the presented framework. The main benefits of adding a third layer include the formalization of the process by using a visual sequence that is also as detailed as the narrative. For the difficulties, the addition of a third layer can increase the time spent at this phase of the project, requiring a new set of skills that not all engineers may possess.**

Palavras-Chave **− Concept of Operation, Model-Based Systems Engineering.**

I. INTRODUCTION

The Concept of Operations (ConOps) is a tool widely used in the early steps of the projects of many systems, as it allows a better understanding of the stakeholder's needs and how the system is expected to be operated after its development. Usually, the ConOps is created using visual and textual elements in a simple and easy-to-understand way.

When using the Model-Based Systems Engineering (MBSE) methodology, it is possible to describe and model the use of a system through the use of sequential diagrams called Scenario Diagrams.

Thus, in this paper, a triple channel cognitive ConOps is introduced: using visual, textual, and model diagrams. The first channel corresponds to the usual developed ConOps, while the second is the textual narrative of the visual ConOps, and the third, finally, is the added modeled scenario developed with MBSE methodology.

The paper is organized in the following way: section two will present how the ConOps is currently developed; section three will explain the methodology that will be used to develop the triple channel ConOps; section four presents a case study for the application of said methodology.

II. CURRENT APPROACH TO THE CREATION OF CONCEPTS OF OPERATION BY THE SYSTEMS ENGINEERING

This section describes the current methods of systems engineering and the definition of the concept of operations, as well as how this concept is currently developed.

A. Systems Engineering

One can define a *system* as a collective of elements or components that must work together concurrently so that a goal or a need is satisfied [6]. That being said, the engineering field that deals with systems needs to be a type of engineering that considers the product as a whole, while also thinking about how each part has to connect with others, allowing the problem to be viewed from many angles so that the solution is as complete as possible.

As said by [2], systems engineering can be defined as a transdisciplinary methodology utilized to obtain systems that satisfy a group of requirements in its totality. This methodology has a very iterative nature, allowing the continuous bettering of the system that is being studied.

Model-Based Systems Engineering is applied to traditional systems engineering to go from a document-based engineering process to a digital-based one. This concept is more profoundly investigated by [1], [3], [4], and [7]. Particularly, the ARCADIA method of utilizing MBSE, with the Capella tool, is used for adding the third cognitive channel.

ARCADIA stands for Architecture Analysis and Design Integrated Approach and was developed by Thales between 2005 and 2010, being an MBSE approach that focuses on successive engineering phases and a separation between the need and the solution [8].

When applied to the Capella tool, which will be used for the modeling of the ConOps scenario, the ARCADIA approach presents five main levels with different diagrams and concepts: the operational analysis, the system analysis, the logical architecture, the physical architecture, and the EPBS [8], presented in Fig. 1.

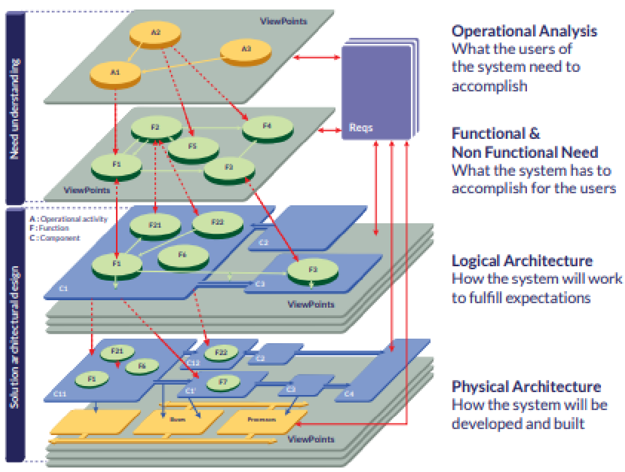

Fig 1. The ARCADIA method for MBSE [10].

The operational analysis consists of an analysis of what the users need to accomplish, so that, at this stage, no mention of the system is made, the actors that interact with the system (stakeholders) are identified, and their interactions are observed.

Now, in the system analysis, it is studied what the system needs to accomplish for the users. That means that the system will be mentioned, but only with an external or a black-box analysis, where only interface functions between the system and the actors are allocated to the system.

In the logical architecture, it is studied how the system will work to fulfill that need. That means that the system no longer needs to be a black box, being able to be divided into subsystems for a very detailed analysis.

The physical architecture studies how the system will be built, adding implementation and technical components. Lastly, the EPBS, or End Product Breakdown Structure, defines what is expected from the components supplier.

With the goal of this methodology being applied in the most efficient way possible, [9] presents two separate approaches: the technical approach and the management approach. The technical approach consists of the engineering and the problem resolution domain, that is, obtaining the correct design for the system. The management approach, on the other hand, needs to maintain the integrity of the system along with the project, being responsible, for example, for complexity management.

The existing complexity in products of engineering is growing with each day, being very easily notable in the aerospace industry. Aircraft, for example, are systems with a very high level of complexity, being formed by a group of many subsystems with many components each, that need to work together and need to be projected to work in that way. That being said, systems engineering, while being a multidisciplinary tool, capable of viewing the whole of the systems, and iterative, has shown more and more qualities that qualify it as a fundamental tool for the development of this kind of system.

B. Architecture and Concept of Operations

As said by [6], the Concept of Operations is a tool used to describe how the system will be used to satisfy the stakeholder's needs after being developed, acting as a basis for many subsequent phases of the project. The concept of operation is, usually, developed sequentially or chronologically, utilizing visual and textual elements and even diagrams to facilitate the understanding of the document.

When developing the concept of operations, it is important to do a scenario exercise, where it is considered not only the usual operation of the system but also the fail, emergency, and otherwise unseen scenarios. This exercise will make the engineering team deal with complex and high-risk projects, making sure all possible operations of the systems are accounted for.

The goal when developing the concept of operations, as said by [2], is to capture the stakeholder's needs, without getting attached to a single implementation solution. That is, by having a well-developed and clear understanding of the concept of operations, it is possible to obtain a system that executes the necessary operation and, in consequence, satisfies the stakeholder's goals and needs for the project.

III. Developing the Triple Channel with MBSE

This section will describe in detail how the triple channel was developed. Firstly, the example used to develop the research will be presented, to obtain the necessary information for the next steps. Then, a sketch of the Illustration Scenario and Narrative will be created, followed by the detailing of how the mission was modeled using Capella and how the Scenario Diagrams were made, and finally, the Illustration Scenario and Narrative will be re-evaluated to agree with the Capella diagrams.

To fully understand the methodology presented and the following section sequence, the diagram in Fig. 2 shows. The letters shown in blue represent the subsections in the sections of the paper, that is:

A. Structuring the ConOps Information;
B. Creating the Illustration Scenario and Narrative;
C. Modeling the Scenario;
D. Structuring the ConOps flow down;
E. Re-evaluating the Illustration Scenario and the Narrative.

While the numbers in orange are important diagrams or steps in the project:

1. Information resulting from interviews and research;
2. Mission and capabilities diagram;
3. Model building in software;
4. State Machine diagram;
5. Scenarios diagram;
6. Illustration Scenario and Narrative.

The necessary information comes from interviews with stakeholders and other interested parties to write a mission statement and define the primary and secondary goals of the mission. This information is then modeled using the mission and capabilities diagram in Capella, which in turn is used to obtain a first sketch of the illustration scenario and the narrative. This diagram is also used in the next steps in modeling the mission in Capella, including the making of the State Machine and the Scenarios diagrams. Lastly, the Illustration Scenario and Narrative are re-evaluated based on the Scenarios and the State Machine diagrams, to align all data and information.

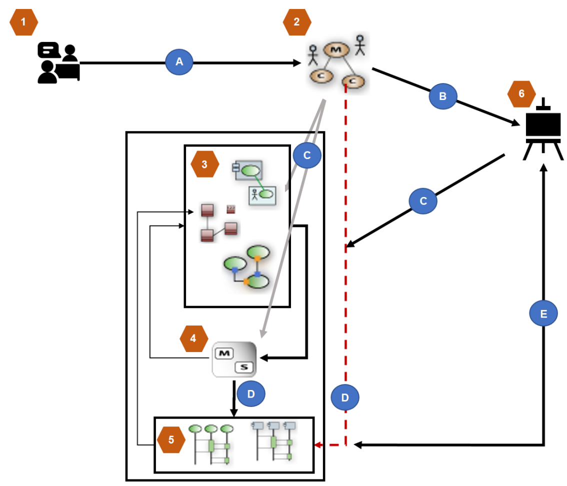

Fig. 2. Methodology Diagram.

A. Structuring the ConOps information

To better visualize the methodology presented in this paper, a case study will be presented in this section and used as an example in the sections. The case that was chosen to be used consists of the hypothetical FireSat space mission, presented in [5] and widely known by the academic community. The mission statement presented by the author follows.

"*Because forest fires have an Increasing impact on recreation and commerce and ever higher public visibility, the United States needs a more effective system to identify and monitor them. In addition, It would be desirable (but not required) to monitor forest fires for other nations; collect statistical data on fire outbreaks, spread, speed, and duration; and provide other forest management data. Ultimately, the Forest Service's fire-monitoring office and rangers In the field will use the data. Data flow and formats must meet the needs of both groups without specialized training and must allow them to respond promptly to changing conditions."* [5]

This mission statement is, as expected, very broad and abstract, expressing the primary need for a system able to perform monitoring of forest fires in the United States. It also states a few secondary goals, including monitoring forest fires in other countries, the type and accessibility needed for the data acquired by the system, and the demonstration of positive actions taken by the government to reduce forest fires.

B. *Creating the Illustration Scenario and Narrative*

This section will describe how two of the three channels of the Concept of Operations for the selected mission were created. When describing the illustration scenario and the narrative, the methodology for the creation of the ConOps used will be the one presented by [9]. It is important that all channels used represent not only normal operational cases of use but also consider situations of failure and emergency.

The author proposes a methodology of six steps that need to be followed to obtain a complete and coherent ConOps document. The steps will be presented below.

1. Mission Scope - The first step presented by the author consists of a deep understanding of the mission scope, the stakeholder's needs, goals, and objectives;
2. System's Operational Environment - The second step includes a description of the current environment of the system, that is, the capabilities currently available to the stakeholders and the characteristics that constraint the current use of the system;
3. Operational Scenarios - The third step consists of building the operational scenarios, this is where the illustration will be created and the narrative will be written
4. Implementation Concepts - The author presents a fourth step that considers the brainstorming for multiple conceptual solutions for the implementation of the system so that the ConOps is not tied to any preconception of the engineers;
5. Documentation - The fifth step includes the formal documentation of the ConOps, which should include every process and information obtained in the previous steps;
6. Validation - Lastly, the author remembers the importance of validating the Concept of Operations before moving on to the next point of the project.

By following this methodology, we will have, in the end, validated documentation of the Concept of Operations and, the main product of interest of this section, an illustration scenario, and a narrative that comprises the operational use of the system being projected.

C. Modeling the Scenario

This section will describe how the third and final channel for the Concept of Operation was obtained. Unlike the other two channels, this last one will be created considering the methodology of Model-Based Systems Engineering with the ARCADIA method, using the Capella tool.

D. Structuring the ConOps flow down

In the end, the three cognitive channels will work in unison to allow a better understanding of the stakeholder's expectations. While the illustration scenario enables the reader to absorb the information visually and sequentially, the narrative allows a greater fluidity and a lot more details to tell the story of the operation of the system.

The last channel, the model scenario, comes to tie the process together by enabling a formal description of the concept of operations that is both sequential and detailed.

E. Re-evaluating the Illustration Scenario and the Narrative

The last step of the methodology presented in this paper, as shown in Fig. 2, consists of a re-evaluation of the illustration and the narrative.

Now that the scenario has been modeled, the illustration and the narrative can be evaluated to be sure that all channels tell the same story and that there are no details that contradict each other.

After this step, the methodology is completed and can be documented as required by the specific project it is being worked on.

IV. Results and Analysis

This section will discuss the results obtained when applying the methodology described in the last sections. First, the Illustration Scenario and the Narrative Concept of Operation will be shown and explained, then, the model version of the ConOps will be discussed.

A. Illustration Scenario and Narrative

To develop these two channels of the Concept of Operations, the first step is analyzing the mission scope. That will be done by writing the mission Need, Goals, and Objectives, which can be visualized in Fig. 3.

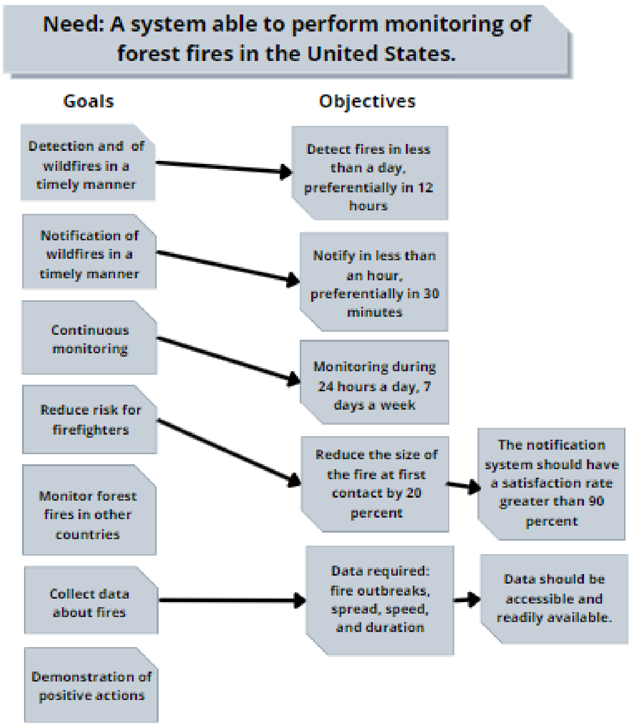

Fig. 3. Need, Goals, and Objectives.

The mission's main need is to be able to monitor forest fires in the United States, as stated in the last section. There are seven written goals, as well as objectives. These were written based on the goals and objectives exposed by [9]. Those goals include the detection and the notification of wildfires, with continuous monitoring, they also mention the reduction of risk for firefighters, the collection of data from the fires, the monitoring of fires from other countries, and the demonstration of positive action taken by the government. All objectives are sourced from one of the goals, describing those in greater detail.

The next step shown in the methodology includes the description of the current and the desired mission environment. Fig. 4 shows the current environment, while Fig. 5 shows the desired one.

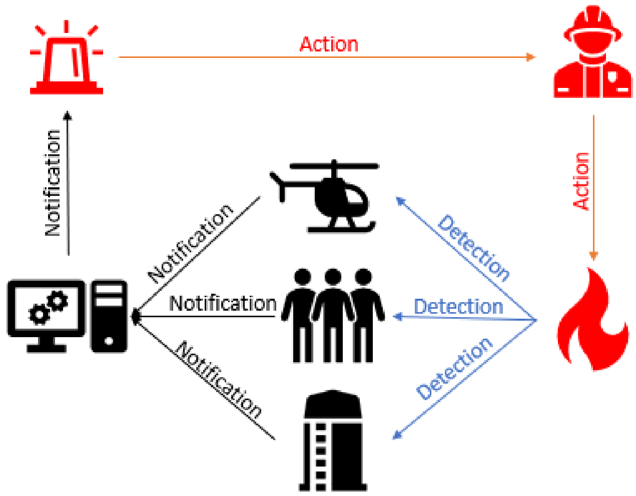

Fig. 4. Current Environment.

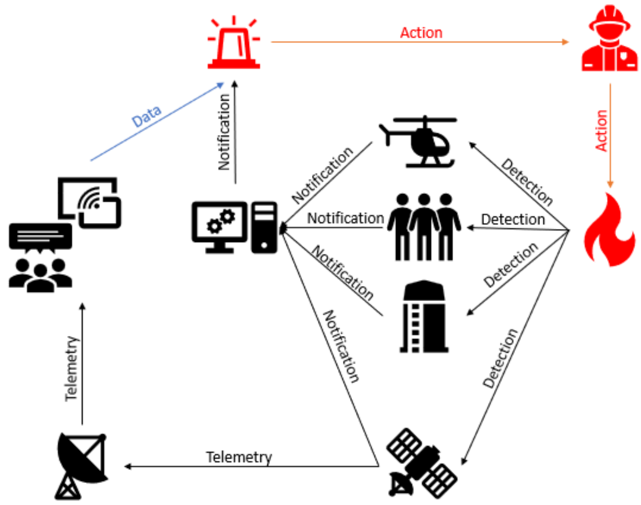

Fig. 5. Desired Environment

The current environment shows the detection of fires being made by a UVA, citizens, or fire watchtowers, that then notify a central office that sends the information to the fire station, which then sends firefighters out to combat the fire. In the desired environment, a satellite will also make the detection of fires and send the notification to a ground station, which will then notify the fire station. In this situation, the satellite also collects data about the wildfires and sends it to the firefighters.

Now that all the information needed is available, the illustration scenario and the narrative can be created. The illustration can be seen in Fig. 6.

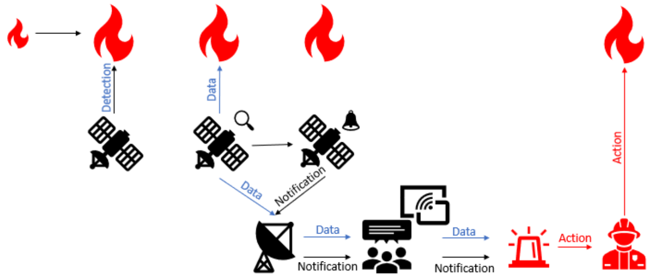

Fig. 6. Illustration Scenario.

To explain the visual ConOps, the narrative will be presented:

"The fire starts and grows up to a size that can be detected. The satellite then detects the fire and collects useful information and the required data. The satellite then sends a notification to the ground station, which in turn notifies the Fire Station, which is ready to take action and sends firefighters to combat the fire. The data goes through the ground station, being processed and analyzed, and then is sent to the Fire Station."

B. Model Scenario

The scenario described in the narrative is presented using the System Analysis layer in Capella. Fig. 7 shows the third channel for the concept of operations.

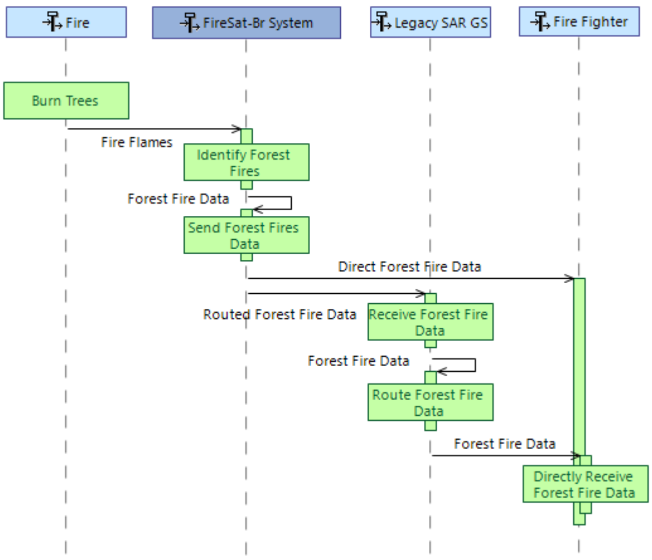

Fig. 7. Model Scenario.

V. Conclusion

The use of a triple-channel approach to the writing of the concept of operations brings many benefits to a system's project. When using an illustration to describe the sequence of the concept of operations, it is possible for the reader, or a person with no connection to the project, to fully visualize how the stakeholders expect to use the system when it is operational, ideally, without a proposed solution yet.

The narrative then comes with the fluidity of the chosen language to help create a story that is shown in that illustration scenario with the possibility of a lot more details. These two channels need to coexist for the reader to fully understand the story that the concept of operation is trying to tell.

The last cognitive channel, the model, helps to formally describe the channel. It has that visual sequence that the illustration has and also the details that the narrative allows. This last channel comes to tie all the channels together and serves as a formal sequence diagram for the documentation of the concept of operations.

Therefore, by using all three cognitive channels, the reader is allowed a mental reconstruction of all the information collected previous to the development of the concept of operations. Being able to have this mental reconstruction is crucial for a full understanding of the stakeholder's expectations, allowing for the project to move on to the next steps with certainty that every party involved with the project has all the knowledge available at the stage.

However many benefits the user of three cognitive channels can bring to a project, it also has a few implementing difficulties.

The most obvious difficulty that can be found in trying to implement this approach is the skill required. Not all systems engineers may have the skills required to create all three channels of the concept of operations, which may result in the need for the qualification of workers and learning new skills to apply this methodology.

Another difficulty found is related to the time required to create the ConOps is considerably greater when adding a model layer to its process, which can greatly impact the time expected at this stage of the project and even in the development time of the project.

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