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Scenario-based Needs Analysis for a Remote Sensing Defense Mission

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Abstract

The first step in the space systems engineering process is to define and scope the mission objectives oriented by the stakeholder's needs. Sometimes the needs analysis effort can be underestimated; specifically regarding to space remote sensing defense missions, characterized by innumerous and in some cases, conflicting needs. The Systems Engineering Office (LSIS) from the Brazilian Institute for Space Research (INPE) proposes the Needs Analysis by Scenarios, flowing down from the operational scenario needs to the mission requirements. The scenario approach proposed, take into consideration three dimensions: 1. the key parameters for remote sensing missions; 2. the typical remote sensing defense missions: Surveillance and Reconnaissance; 3. the main defense targets and its sensing features. The proposed approach helps to maintain traceability from stakeholder needs to mission requirements, granting the objective delimitation of the mission scope. The knowledge base created represents a tool to support the trade-offs during the development process, allowing the identification of technical decision impacts in the stakeholders needs. The methodology and information developed allow the analysis for other remote sensing defense missions, independently of the solution.
Keywords: Needs analysis; operational scenario; defense mission; remote sensing, mission definition.

Acronyms/Abbreviations

Brazilian Institute for Space Research (INPE)
Intelligence, Surveillance, and Reconnaissance (ISR)
International Council on Systems Engineering (INCOSE)
Department of Defense (DoD)
Ground Sample Distance (GSD)

1 Introduction

How to define the mission, its statement, objectives and scope? Some authors, as Larson et al. [1], consider the stakeholder needs analysis as a starting point. Larson et al [1] state that the process for a space mission starts with the needs as an input. They also present an abstraction of its framework, which initiate with the understanding of the mission, operational capability and the market opportunity. In defense missions, the definition of the mission and operational capabilities can be a representative effort within the development process, especially in countries where the ownership of defense or even national space technology are minimum or none. This lack of technology makes the country needs to be very broad. Also, the needs come from heterogeneous defense stakeholders having the same weight or priority (e.g. army, navy, and air forces). All these factors together, make the synthesis of the needs and the characterization of the mission to be a complex process; which demands time and a structured analysis to scope it.

Figure 1 represents graphically what implies to synthetize those user needs taking in consideration aspects that constraints the needs in the analysis like the programmatic requirements and the technical feasibility. In some cases, the term "needs" as an input on the systems engineering literature, can be misinterpreted with just the top of the iceberg.

Figure 1. User needs synthesis

2 Process Context

The definition of a mission requires balance and iteration between: 1. what the user-stakeholder wants, 2.

what the program-stakeholder wants and can afford; and 3. what is technically possible within the schedule, cost and technology available. These three aspects, operational needs, technical feasibility and programmatic requirements, must be analyzed on an integrated approach in order to define the mission that better integrates the three of them.

The following approach proposes this integrated analysis. It assumes that the mission needs, which come directly from the stakeholders, are not easily identified neither clear, organized and prioritized by them. “Stakeholders often have trouble articulating their requirements. They may know what they want or what’s wrong with what they have, but expressing these ideas as succinct, actionable requirements isn’t always easy”. [1]

Figure 2 illustrates the context of the scenario-based needs analysis and its iteration with the other principal analyses during the conceptual phase: technical feasibility and programmatic requirements analysis, and its interaction with the mission stakeholders until the mission requirements are defined. There are two kinds of stakeholders at this initial phase. The stakeholders that interact with the scenario-based needs analysis are those closely related to the operational needs. The stakeholders that interact with the programmatic requirements analysis and the definition of the mission are those stakeholders belonging mainly to strategic defense areas and the sponsors of the programm.

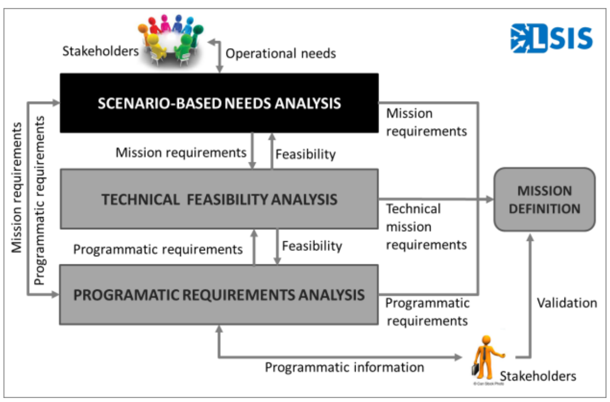

Figure 2. Process context

2.1 *Scenario-based needs analysis*

The stakeholder requirements definition process, according to INCOSE [2], which proposes a generic systems engineering model, “…analyzes and transforms these (needs, expectations and desires) into a common set of stakeholder requirements that express the intended interaction the system will have with its operational environment and that are reference against which each resulting operational service is validated.” According to Larson [1], a space systems engineering reference, “customer expectations, established by the mission need statement or capability definition, represent the problem space for systems engineering.”

The scenario-based needs analysis proposed aims to analyze the mission needs, i.e. the stakeholder operational needs. It focuses in understanding the context of the system’s use and the problematic that must be solved. This process interacts directly with the stakeholders and it helps to synthetize and translate their needs into a technical language for the design team responsible for the technical feasibility analysis.

The outputs of this analysis are the mission statement and a set of mission requirements coming directly from the stakeholders. These requirements define the operational needs, i.e. the capabilities that the solution must accomplish.

This analysis supplies mission requirements for the technical feasibility analysis and for the programmatic requirements analysis. It gives a better understanding of the problem that could impact directly into the programmatic requirements. Furthermore, the generated information could even make the stakeholders to reconsider some of these types of requirements.

2.2 *Technical feasibility analysis*

A feasibility analysis aims to assess the likelihood of achieving some estimated performance parameters. This analysis either confirms that the estimated values are probable to be achieved or provides alternatives that have a higher probability of achievement. The feasibility analysis explores if performance parameters have been achieved before, if current technology supports the desired performance, and some other considerations, which helps in determining the risk, cost, schedule or quality attributes of the project. The feasibility analysis intends to look at some characteristics, such as the basis and the realism of the estimates, the confidence in the estimation, the validity or changes in assumptions, and comparisons of related performance or other relevant parameters. [3]

In the context of this process, the technical feasibility analysis is performed to confirm or provide alternatives to the operational needs (e.g. temporal resolution, spatial resolution, or areas of interest) identified in the scenario-based needs analysis. The technical feasibility analysis also inputs programmatic constraints from the programmatic requirements analysis that limits the solution space, and thus, the scope of the feasibility analysis. As a hypothetical example, it can be imagined that military users state that they need to obtain images of 1m-spatial resolution over the same geographical location with a periodicity of 1 week; then, the feasibility analysis reveals that this is unachievable by using a single satellite. It can be imagined also that budget constraints do not allow considering a constellation as a feasible solution. Consequently, further negotiations with the stakeholders are required before setting a value for the spatial and temporal resolutions requirement value.

The technical feasibility analysis consists in the following two activities: a market study and a technical assessment.

The market study helps to identify what the typical features of remote sensing satellites are, such as the typical values of their capabilities or the typical relation between those capabilities and the satellite classes (e.g. large satellites, small satellites, minisatellites, or microsatellites). Some of the main capabilities that could be considered in the market study are the focal length, pixel pitch, and field of view, since they affect directly the ground sample distance and the swath of a satellite orbiting the Earth, and consequently, the spatial and the temporal resolution.

Then, the technical assessment aims to measure the performance that would be expected from a satellite with the typical capabilities values extracted from the market study. This assessment could be performed for any satellite class that has been identified as a potential solution. For quantifying the resulting performance, calculations such as those suggested by Wertz [4] as well as orbit simulations should be performed. The outcomes of this assessment allow reviewing the operational needs, and consequently, confirming those needs or proposing alternative needs to the stakeholders for further reconsideration. This technical assessment is sometimes referred by space references as mission analysis.

2.3 Programmatic requirements analysis

The programmatic requirements do not come from users and neither from the technical team. However, they also drive the mission definition with the same weight as the technical and user aspects do. These requirements concern about cost, schedule, business and national strategic aspects that usually come from top stakeholders e.g. sponsors, high authorities, national programs and strategies, etc. Among the programmatic requirements, defined as characteristics or nonfunctional needs by Larson et al. [1] there are organizational, technological, statutory or regulatory, standards and protocols, cost and schedule constraints, acquisition or development strategy, etc.

The programmatic requirements can also consider those that Larson et al. [1] call as legacy resources, processes and limitations, i.e. the existing resources that must be considered for elaboration of the alternative concepts.

In this case, the programmatic requirements analysis inputs requirements to the technical feasibility process mainly with issues related to cost, schedule, acquisition strategy, etc. It also inputs requirements to the needs analysis that constraint the needs or group of needs.

2.4 Mission definition

In this context, it is considered that the mission is defined when the mission requirements, technical mission requirements, and the programmatic requirements have iterated within the process, have reached a mature state, and the mission stakeholders have validated them.

The three types of mission requirements are as follows:

Mission requirements: those that represent the operational needs, expected capabilities, and mission objectives.

Technical mission requirements: those related to the technical parameters that need to be achieved to satisfy the capabilities and the mission architecture.

Programmatic requirements: Those constraining the alternative concepts, mainly with cost and schedule.

3 Scenario-based needs analysis process

The objective of the scenario-based needs analysis is to understand the needs and structure them on a scenario basis, helping to scope the problem domain that will be attended by the system implementing the solution. It focuses on the mission stakeholders needs. The technical and programmatic issue will iterate with the analysis thus refining and delimiting the mission definition and its stakeholder requirements.

The operational scenario description is the base of the analysis approach. All the elicited information along the process is incorporated to the scenarios with the intention to analyze them individually and to develop a remote sensing characterization of each. This characterization is based on the attributes that support the parameters definition for the remote sensing mission.

The integrated analysis within the scenario happens on an incremental manner as shown in Figure 3.

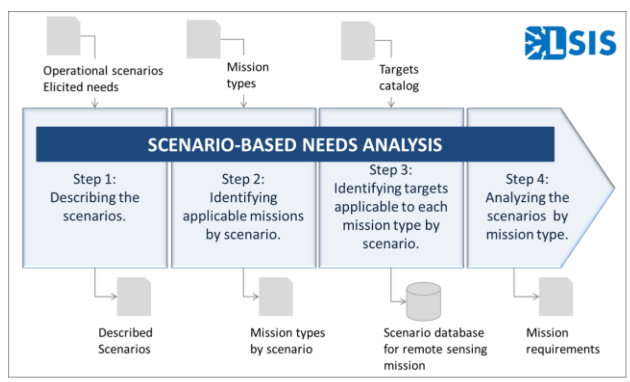

Figure 3. Scenario-based needs analysis process

The core of the process is the integration between the different vectors involved in the analysis within the scenario, to obtain structured information that helps analyze the needs from their operational point of view and to support the decision making process during the mission definition. The characterization of the scenarios for a remote sensing defense mission depends on the following three vectors that will be described in sections 3.1, 3.2 and 3.3:

- Defense operational needs
- Remote sensing defense mission types
- Defense targets and its sensing attributes

3.1 Step 1: Describing the operational scenarios

In the context of this proposed approach, an operational scenario represents a defense operation of any of the defense organizations previously stablished by their doctrines.

The objective of this step is to understand the operations activities developed by the defense organizations, the context and impact of the scenario and the use of the remote sensing system in each defense operational scenario comprehending what the users need to identify and in what operational environment. This type of information guides the interpretation of what is needed in terms of capabilities. The remote sensing targets for defense purposes are so many and diverse that the capabilities needed are many and some of them are conflicting by their nature.

3.1.1 Needs sources

In general, after defining the mission stakeholders, the first action to be taken is to define the information sources and to analyze them. This research or study phase will introduce the systems engineer to the problem and its context, and it helps to give him the big picture of the problem that is being analyzed. For defense missions, the needs that will be analyzed can come from different sources, such as:

a. Mission stakeholders
b. Strategic national needs
c. Existing or planned National Defense Programs
d. Operational scenarios
e. Defense doctrines
f. Defense target catalog

3.1.2 Needs elicitation through operational scenarios

After the research and the needs contextualization, it is important to select the defense operational scenarios that would be included in the analysis. Developing the totality of defense operational scenarios would be expensive and time demanding, so it is recommended to start with a set of representative scenarios in relation to a strategy, a major need, a program or any other criteria that has been already scoped within the programmatic drivers. This would help to prioritize the most representative operational scenarios.

The construction of the scenario focuses in specific information pre-defined for its purpose. The information elicited can vary depending on each case. The following are some examples of the type of information for the scenario description that support the analysis: Stakeholder owner of the scenario, description of the scenario, strategic interests involved, area of interest, applicability of remote sensing, etc.

3.2 Step 2: Identifying applicable defense remote sensing mission type by operational scenario

In terms of remote sensing defense missions, there can be considered two types of typical mission: Surveillance and Reconnaissance. These types of mission support intelligence activities and are treated as a whole on the defense jargon as Intelligence, Surveillance, and Reconnaissance (IRS). The Department of Defense (DoD) from de United States defines IRS as "an activity that synchronizes and integrates the planning and operations of sensors, assets, processing, exploitation, and dissemination systems in direct support of current and future operations. This is an integrated intelligence operations function.". [5] . The DoD also defines the terms separately as follows:

"**Intelligence:** The product resulting from the collection, processing, integration, evaluation, analysis, and interpretation of available information concerning foreign nations, hostile or potentially hostile forces or elements, or areas of actual or potential operations." [5]

"**Surveillance:** The systematic observation of aerospace, surface, or subsurface areas, places, persons, or things, by visual, aural, electronic, photographic, or other means." [5]

"**Reconnaissance:** A mission undertaken to obtain, by visual observation or other detection methods, information about the activities and resources of an enemy or adversary, or to secure data concerning the meteorological, hydrographic, or geographic characteristics of a particular area." [5]

A space mission can play an important role on reconnaissance and surveillance activities since it supports intelligence activities through sensors placed on ground, sea, air or space technologies. Consequently, the proposed process for scenario-based needs analysis is based on these two classifications of defense space missions.

3.2.1 Definition of applicable defense remote sensing missions by scenario

The Surveillance and Reconnaissance missions can be subdivided depending of the criteria established by the systems engineering and drivers already stablished for the analysis. For instance, it can be subdivided by the type of the targets that need to be sensed. This refinement enables the delimitation of the mission alternatives and also helps to structure the targets by similar features.

For each alternative mission within the scenario, it must be defined the operational needs an parameters applicable to that mission. The generated information will enable the analysis from the type of mission point of view described on step 4 (section 3. 4)

The systems engineer must establish critical parameters for each mission by the scenario that will help to characterize the defense mission types. Some of these parameters could be the periodicity of the scenario, revisit needed, scene size, etc.

3.3 Step 3: Identifying targets applicable to each mission type by scenario.

The targets are one of the main links between the stakeholder operational needs and the technical interpretation of those needs since each target is characterized by remote sensing features or parameters that will help to translate the needs into technical requirements.

Once the need for a remote sensing system is identified in step 1, and the type of mission is defined in step 2, it is time to identify the different targets involved in the scenario for each remote sensing mission type. For each mission type, the targets can be subdivided in two classes: continuous field targets and discrete object targets.

3.3.1 Discrete object targets

The discrete object targets refer to specific objects with defined shape and usually human-made features. The targets can have a previously classification established by the organization. An example of this classification can be by target type:

a) Critical infrastructure
b) Human/Animal
c) Infrastructure
d) Transport

For each target, there are some features or characteristics that need to be detailed to enable the analysis and the transformation of the needs into technical parameters, thus being able to establish the technical mission requirements. The features in analysis must be previously stablished by the systems engineer. An example of the considered features is:

a) **Operational need**: it details specifically what is the need in relation to that target. What does the stakeholder wants to be able to do.
b) **Accuracy level:** sometimes it is possible to categorize the operational need with an accuracy level of reconnaissance. According to the Air standard 80/15 [6] , there are four levels of accuracy for a target sensing:
    - Detection: In imagery interpretation, the discovering of the existence of an object but without recognition of the object.
    - Recognition: The ability to fix the identity of a feature or object on imagery within a group type, i.e., tank, aircraft.
    - Identification: The ability to place the identity of a feature or object on imagery as a precise type, i.e., T54 tank, MIG21J.
    - Technical Analysis: The ability to describe precisely a feature, object or component imaged on film.
c) **Ground sample distance (GSD):** The size and level of accuracy require a specific GSD, which need to be defined to orientate the analysis by mission type on step 4.

3.3.2 Continuous field targets

The continuous field targets refer to great areas and land patterns and its delimitation. The classification of this type of targets can be established by the users themselves, in case they already have a structure that the organization is used to work with. An example of this structure is as follows:

a) **Application:** These categories begin to narrow the characterization of the mission, since the defense purposes covers diverse and multiple types of applications used for civil purposes. The following categories are based on the Earth Topics defined by the European Space Agency[7]:
    1. Land
    2. Natural disasters
    3. Snow & ice
    4. Water & coast
b) **Operational need:** The description of what needs to be observed. The operational scenario has a great impact of the need description, thus influencing the other characteristics.
c) **Spectral resolution:** The spectral resolution needed to sense the target
d) **Ground sample distance (GSD):** this need to be defined so as to orientate the spatial resolution during the analysis by mission type on step 4.

3.3.3 Summary for each mission type

With the information generated until this point it is possible to establish the spectral resolution and GSD required for each mission type; based on the list of targets and its features. This information supports the following needs analysis on step 4.

3.3.4 Target Catalog

The target catalog is a register of the targets, its features and signatures. If it does not exist yet in the organization, this process will support the creation of it and it will become an asset to the organization. Thus, as new needs or opportunities emerge within the organization, the analysis process will become more agile and refined with new information and/or more refined data incrementing the existing catalog. It is convenient that the technical analyst of the image supports the development of it, since they have the knowledge and experience analyzing the images.

3.4 Step 4: Analysing the scenarios by mission type

At this point, the **operational scenarios** are described and oriented to remote sensing applications. The **defense mission types** are identified on each scenario and characterized with the operational needs. These characteristics will drive the technical analysis and its technical mission requirements. Each scenario is detailed with the **targets** that the stakeholder is willing to sense for that specific case. Each target brings **features and signatures** related to remote sensing characteristics that will also support technical analysis and technical mission requirements definition.

Until now the process was being driven by the operational scenarios and all the possible information was being elicited in an integrative and progressive approach. Now, the final analysis is driven by the mission types identified in the operational scenarios. The information now is seen through a new glass. The objective of step four is to analyze the group of scenarios by mission type.

To synthetize the needs structured by scenarios from a mission type point of view is required to now structure the scenarios by mission type. This reorganization will help to synthetize the parameters contained on all the scenarios within each mission type in order to compare them. As shown in the example illustrated on Table 1.

SCENARIOS	MISSION TYPES				SCENARIO PARAMETERS			
	A	B	C	D	Spatial Resolution	Spectral Resolution	Revisit	etc
1	X				5	VIS, NIR	None	
			X		0,75	PAN	None	
2			X		15	VIS, NIR	High	
		X			1	PAN	Moderated	
n								

Table 1. Example of a scenario analysis by mission type

The scenario parameters that better drive the analysis can be defined by the systems engineers together with the technical team and the stakeholders. The operational scenarios developed could contain additional parameters that can be considered for further refinements.

After the correlation between operational scenarios and defense mission types and the targets allocation to each mission, it is possible to analyze each alternative mission types. Thus, each alternative contains parameters that will drive the mission statement and mission requirements. The parameters that could be considered are:

a) Scenarios considered
b) Stakeholders attended
c) Spectral resolution to attend all the scenarios
d) Spatial resolution to attend all the scenarios
e) Targets attended

All the resulting missions can be alternatives to become the mission. Each of these alternative missions will have its own mission statement and mission requirements. The programmatic requirements and technical feasibility will help to reduce the mission alternatives and the scope of the mission. At the end of the process is required the validation of the stakeholders.

4 Results and discussion

As results of the scenario-based needs analysis the proposed process accomplishes some of the outputs defined by INCOSE [2] in the Stakeholders Requirements Definition Process: the stakeholder requirements, the traceability of each stakeholder and means to validate the solution. It also supplies enough information to elaborate the operational concept of the mission and to support the stakeholders in the measurements of effectiveness (MoEs) definition.

The scenario based approach provides means to assess mission accomplishment. The structured information by scenario and by mission types with its targets helps to validate the capabilities offered by a specific solution, being able to identify what is covered and what is not, even to a target level; thus supporting the making decision process. Also, the approach supports the trade-offs between alternative solutions; enabling the identification of the impact that technical decisions may cause in the attendance of the stakeholder requirements, since there is the traceability form stakeholders needs, stakeholder requirements and technical parameters of the remote sensing mission. Finally, it is possible to measure the level of attendance to each stakeholder since the needs maintain traceability to the owner stakeholder.

The process supports the transformation of the stakeholder's operational needs into technical requirements always guiding the elicitation process to obtain the critical information (defense type mission parameters and targets definition) that will help define the technical requirements. Coupled with the fact that the individual analysis of each scenario can help to identify alternative solutions different from space-borne platforms; thus, providing optimum solutions to specific scenarios.

5 Conclusions

In essence, the proposed process for needs analysis on a scenario based approach, can demand a considerable effort from systems engineers and stakeholders, not to mention the schedule and cost, but the data base that is built through the analysis can be considered as an important asset for the organization. This base of knowledge becomes a start point to support other missions definition, since it manage a broad quantity of needs and applications for remote sensing missions, not necessarily attended by a space-borne platforms.

This process herein proposed contributes when the needs are broad and competing between them, as is the case of the needs for defense purposes. In the defense area, the mission stakeholders have needs with equal weight but with different and sometimes opposite solutions. Additionally, the process facilitates the structure of these needs in forming clusters of similar needs from their remote sensing point of view and always maintaining the traceability to each need's owner and the rationale of the decisions made during the conception process.

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