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Chapter

# A Novel Space Systems Management Methodology Based on Shortcomings and Strengths of Conventional System Engineering Tools Used in a Design Thinking Framework

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## Abstract

In this chapter, several systems engineering tools are presented and analyzed to determine shortcomings of these tools to improve the efficiency and efficacy of them working together in a modified design thinking methodology framework for space systems management. The space systems projects impose a high risk in all its stages, so that it is very important to reduce errors as possible based on activities that ensure the adequate project performance. Finally, specific systems engineering tools are used in particular stages and sub-stages of the proposal design thinking framework depending on the shortcomings and strengths of each one. This proposal framework accelerates the conventional process for a space project that usually requires a lot of resources and it is not suitable for both emerging countries and space agencies.

**Keywords:** systems engineering tools, design thinking, space projects, shortcomings-strengths, efficiency

## 1. Introduction

From its origins, the human being has looked for ways to transform nature, for that reason his ingenuity and creativity have been the transforming force of the world. Thus, the way of taking ideas to concrete facts using scientific knowledge is called engineering. In a more technical way, engineering is a discipline that uses scientific and technical knowledge to imagine, design, create, make, operate, maintain and dismantle complex devices, machines, structures, systems and processes that support human effort [1]. On the other hand, the set of parts that interact with each other to achieve an objective is called system [2], which can also be a combination of

interacting elements organized to achieve a purpose [3]. The combination of these two words is known as systems engineering and it is the structured application of scientific knowledge for the design, creation and management of a set of interacting elements to achieve an objective. The beginnings of systems engineering go back to the effects of the World War II in the 1950s and 1960s when systems engineering was named for first time in several publications as a distinct discipline. The recognition of systems engineering as a unique activity evolved for the rapid growth of technology and its application to major military and commercial operations during the second half of the 20th century [4]. In the past years, systems engineering was closely linked to the methods used in electronic communications and aerospace engineering, and that is why it obtained its place within these disciplines since it was the responsible of finding solutions to reduce levels of complexity in the situations of human-machine interaction [5]. Currently, there are several definitions about systems engineering but the most important is defined in the systems engineering manual of the National Aeronautics and Space Administration (NASA), where it describes that systems engineering "is a methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system" [6]. It is important to mention that the systems engineering objective is to ensure that the system has been designed, constructed and operated in such a way that it fulfills its purpose in the most profitable way possible, contemplating performance, cost, schedule and risk [6]. The aforementioned to produce systems that satisfy the needs of customers and increase the likelihood of system success [7]. In addition, innovation is an important aspect, therefore, professional human resources are required to develop management and engineering solutions for actual and future complex space systems challenges. Thus, the systems engineer must be able to apply his work, understand and recognize a problem, problematic situation or process in his context to apply, adapt and manage technological solutions. In particular, systems engineers usually begin their studies with an Engineering in electronics, mechanics or any of their interests and then choose to look for certifications such as the International Organization of Systems Engineering (INCOSE) or even for postgraduate studies in systems engineering [8].

Unlike the Project Manager, a systems engineer has a fundamental knowledge associated with the principles of engineering management. However, it is possible that the role of a systems engineer is not fully understood or appreciated since it is less defined than a Project Manager in many organizations [8]. In fact, the perspective of a project manager on a problem is very different in comparison to the perspective of the system engineer and, based on that they do not usually work together, there is not an "optimal solution," that could be achieved using tools and techniques of both systems engineering and project management [9]. Projects related to the aerospace sector can be more successful having systems engineer at the team, since they know the technical domain: hardware and software. Systems engineering provides a framework for problem solving, if a system or problem is more complicated, the processes are more useful for systems engineers to do their job and improve the overall performance [10]. The space systems engineering is defined as the art and science of creating space systems capable of comply strict requirements, through the interdisciplinary participation of various areas of engineering, such as: electrical, mechanical, electronic and computing [11]. The mentioned is reached based on a team activity in which the people involved are aware of the relationship between specialties and their roles in development as an organizational process. It can be said that the space systems engineering consists on designing, building and managing the efforts for the administration of the mission and the space operations, i.e., helping the team to implement the necessary techniques to deliver the project on time and under the budget. Thus, the objective of

space systems engineering is to apply the principles, methods and tools of systems engineering necessary to transform the fundamental technical, economic and social requirements into an integrated space system solution [12]. This integration includes hardware, software and human resource, integrated in a clearly articulated value proposal and in the general architecture of the system. In particular, the space systems engineers help to the design effective space missions because they are focus on overall activities (e.g., verification, validation, operations, among others). They must ensure that the cost estimation of the project/program life cycle is within the budget and current NASA policies, which establish that projects must submit sufficient budgets to guarantee a 70% probability of achieving the objectives without exceeding the budget [6]. This is the reason why it is necessary to establish processes to estimate, evaluate and control costs in each phase of the project.

The "program/project life cycle" mentioned above is one of the fundamental concepts used by NASA in systems administration, which consists in the categorization of everything that must be done to achieve a program or project in different phases, separated by key decision points (KDP) [13]. The KDP refers to the moments where the leader determines the preparation of the program or project to move on to the next phase; if a program or project does not approve one of the KDPs, it is possible to try again afterwards or simply finish the project [13]. Remember that all systems begin with the recognition of a need or the discovery of an opportunity and advance through various stages of development to a final disposition [6]. This program/project life cycle is divided into two main segments (formulation and implementation) and these in turn into seven phases (conceptual studies, concept and development of technology, preliminary design and completion of technology, final design and manufacturing, system assembly, integration-test-launch, operations and maintenance, ending) [14]. In addition, there are metrics for the evaluation of systems engineering processes generally divided into three categories. These metrics measure the progress of the systems engineering effort divided in the quality of that process and those that measure its productivity (progress in the schedule ($S$), quality ($Q$ ) and productivity ($P$)). Additionally, these metrics attempt to quantify the efficiency and productivity of the process and its organization, and are often very useful for engineers in space systems [6]. According to the metrics mentioned, the quality metrics relationship should serve to indicate when a part of the systems engineering process is overloaded and/or breaking down. Also, these metrics can be defined and tracked in different ways, e.g., the metrics related with the productivity provide an indication of the systems engineering output per input unit. Although there are more sophisticated input measures and the most common being the number of hours of systems engineering devoted to a particular function or activity. Finally, the schedule-related metrics can be depicted in a table or graph of planned quantities versus actuals quantities, for example, comparing planned number of verification closure notices against the current one [6].

On the other hand, innovation is defined as a process to convert opportunities into practice widely used [15]. Therefore, systems engineering and innovation have common characteristics in many aspects, among them there is a successful system [16], so innovation is also very important in the engineering of space systems. In addition, creativity and innovation are the key in most levels of engineering education, although these topics are rarely expressed, researched, and studied explicitly during the career [17]. Without training in the fundamentals of creativity, only 3% of the population associate creativity and engineering [18]. Engineering education is a paramount in providing the nation with innovative, creative, and critical thinking human capital that contributes to sustainability of the economy [19]. The need for creativity in engineering has led to the development of a lot of creativity

support tools to enhance the creative design process. In addition, these tools not only address technology for the creative process, but also include measurement for assessment [17]. Currently, there are several methods of innovation, however, the one that matters to us in this work is the method of design thinking. Design thinking is a methodology that consists of thinking as a designer, it is the way to solve problems reducing risks and increasing the chances of success, focusing on human needs to reach a humanly desirable technically viable and economically profitable solution [20]. The design-thinking ideology asserts that a hands-on, user-centric approach to problem solving can lead to innovation, and innovation can lead to differentiation and a competitive advantage [21]. The important aspect about the design thinking method is its emphasis on the understanding and commitment of the user from the start, it is also particularly useful for engineers, who often see the process of innovation from a perspective of technological push [21].

In particular, the design thinking methodology involves six stages (see **Figure 1**) [22]. This methodology is developed following a process in which five of its important characteristics are valued: the generation of empathy (knowing the people and the users, understanding the client not as a client but as a human being, as a person who moves and lives in a context), teamwork (interdependent persons that are spontaneously and naturally coordinated, with the motive of common project [23]), the generation of prototypes (execute vision since seeing and feeling a prototype has more value than an image printed on a paper), and environment that promotes playfulness and techniques with great visual content (see **Figure 1**) [24]. It should be emphasizing that innovation methodologies are part of systems engineering because they support their practice, however, systems engineering makes the tools used in innovation methodologies more effective and efficient [25]. Therefore, innovation is important in the engineering of space systems. In addition, projects in the space sector are very important and, considering that the technology used changes very quickly, the implementation of innovative techniques is essential so as not to degraded the overall performance. Finally, the studies of analysis, architecture, synthesis and compensation used in space systems engineering directly support innovation and changes management through configuration management. Also explains the evolution of data and information through data management and joining components integration, verification and validation in the innovation process [16].

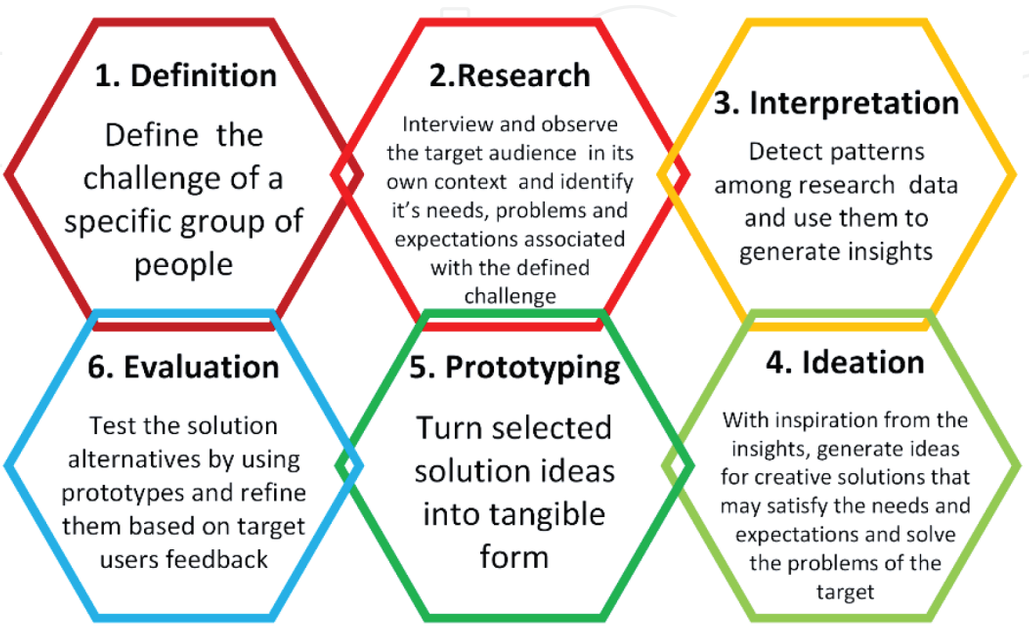



**Figure 1.**
*Design thinking stages. Own elaboration. Information retrieved from [22].*

In this chapter, a realization of a framework for the development of space projects using the systems engineering tools and the bases of the design thinking methodology is proposed. This methodology will serve as support or guidance for countries that are beginning in the development of space projects and do not have many resources, this is because currently there are only work methodologies proposed by NASA and European Space Agency (ESA) that contemplate an important diversity of resources. The general structure of the document is as follows: Section 2 presents and analyzes the traditional qualitative and quantitative tools for space project management and their shortcomings, Section 3 shows the methodology proposed for the administration of space projects based on the design thinking methodology and analyzes the relevance and repercussions of the proposal. Finally, Section 4 presents the conclusions and future research and activities to be considered related to the issue and proposal.

## 2. Qualitative and quantitative tools for space project management

### 2.1 Qualitative tools

Qualitative tools or methods generally help to identify scenarios that contribute to potential risk, providing an input to quantitative methods and supporting quantification based on the measurement of technical performance [6]. In general, there exists a lot of qualitative tools used in project management, but only a few tools with potential use in space project management will be described.

#### *2.1.1 Risk matrices*

**Figure 2** shows the risk matrix "N×M" that helps to manage and communicate risks, since it combines qualitative and semi-quantitative probability measures with similar consequences. A risk matrix helps to track the status and effects of risk management efforts, as well as to communicate information about the status of risks [6]. The risk matrix should contain key information about the description of the risk regarding to cost, time, quality, criticality of the risk, summary of the

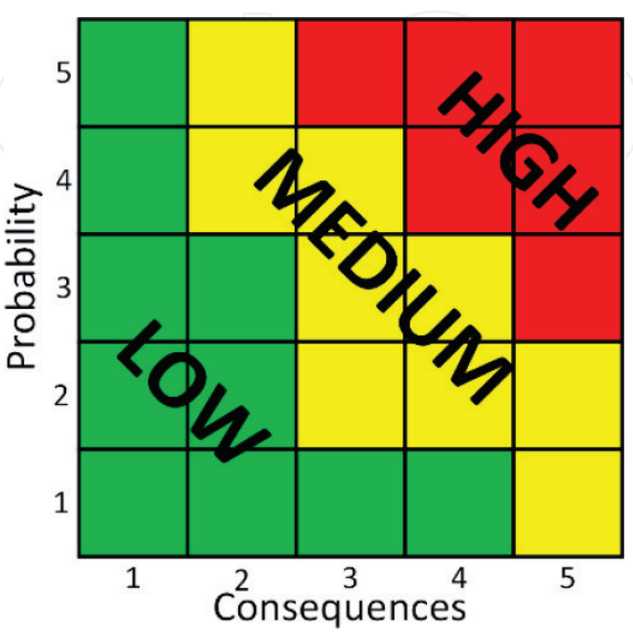



**Figure 2.**
*Risk matrix. Own elaboration based on [6].*

possible causes of the risk, consequences, impact on the success/costs of the project, probability of risk occurrence, evaluation of the risk effects based on predefined criteria, description of preventive technical measures, measures to control and countermeasures that should be initiated if the risk occurs. Classification level for risk matrix are shown in **Table 1**.

As each project can have its own parameters and keywords, the information used by NASA and the US government agencies will be used as a reference [6]: (a) green color (low risk): means that there is reduced or no potential for cost increase, interruption of the schedule or degradation of performance, therefore, the actions taken are important to control an acceptable risk; (b) yellow color (moderate risk): means that it may cause an increase in cost, interruption of programming or degradation of performance, it may require special action and management attention to manage the risk; (c) red color: means that a significant increase in cost, interruption of programming or degradation of performance is highly possible. Thus, important additional actions and high priority attention will be taken.

*2.1.2 Failure modes and effects analysis*

The failure modes and effects analysis (FMEA) is used to identify the possible failures in the process, as well as the effects and causes. Using the FMEA, preventive actions for various tasks can be found and decrease the risk of making mistakes. An FMEA can be used to develop policies, specifications and controls that can avoid the negative consequences of an event. Using this method can be sufficient to prevent or mitigate failures, thus avoiding costs or irreversible damages [26]. The benefits of the FMEA when done correctly are: confidence that all risks have been identified early and appropriate countermeasures, priorities and rationales for actions to improve products or processes, reduce waste, rework and manufacturing costs have been taken, preservation of the knowledge of the product and the process, reduction of failures in the field and cost of guarantee, documentation of risks and actions for future designs or processes [27]. An example of FMEA format is shown in **Figure 3**.

The determination of the risk priority number (RPN) is done by multiplying the values of severity, occurrence and detection, using the information presented by **Tables 2–4**, respectively.

| # | Consequences | Probability |
|---|---|---|
| 1 | Despicable | Rare |
| 2 | Minors | Unlikely |
| 3 | Moderate | Possible |
| 4 | Greater | Very likely |
| 5 | Catastrophic | Almost sure |

**Table 1.**
*Levels of classification for risk matrix.*

Process:
Institution:
Responsible:
Core Team:

Prepared by:
Date:
FMEA original date:

| Process | Potential failure mode | Potential failure effects | Severety | Potential causes | Ocurrence | Current controls | Determination | Risk Priority Number (RPN) | Actions taken |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

**Figure 3.**
*Example of FMEA format. Own elaboration.*

### *2.1.3 Ishikawa diagram*

Ishikawa diagram (shown in **Figure 4**) was invented by chemist Kaoru Ishikawa who noted that this diagram can be used as an analytical tool in project management and quality search [29]. This diagram is also known as a fishbone or cause-effect diagram and it presents schematically the possible causes of a problem. It can

| Severity | | |
|---|---|---|
| **Effect** | **Criteria: Severity of Effect** | **Rank** |
| Dangerous without warning | The highest severity rating of a failure mode, which occurs without warning and the consequence is dangerous. | 10 |
| Dangerous with warning | Classification of higher severity of a failure mode that occurs with warning and the consequence is dangerous. | 9 |
| Very high | The operation of the system or product is broken down without compromising safety. | 8 |
| High | The operation of the system or product can be continued, but the performance of the system or product is affected. | 7 |
| Moderate | The operation of the system or product continues and the performance of the system or product is degraded. | 6 |
| Low | The performance of the system or product is seriously affected and maintenance is needed. | 5 |
| Very low | The performance of the system or product is less affected and maintenance may not be necessary. | 4 |
| Less | System performance and satisfaction with a minor effect. | 3 |
| Very minor | System performance and satisfaction with a slight effect. | 2 |
| Any | Any. | 1 |

**Table 2.**
*Severity levels. Own elaboration based on [28].*

| Occurrence | |
|---|---|
| **Criteria:probability of failure** | **Rank** |
| Extremely high: almost inevitable failure | 10 |
| Very high | 9 |
| Repeated failures | 8 |
| High | 7 |
| Moderately high | 6 |
| Moderate | 5 |
| Relatively low | 4 |
| Low | 3 |
| Remote | 2 |
| Almost impossible | 1 |

**Table 3.**
*Levels of occurrence. Own elaboration based on [28].*

be said that the Ishikawa diagram does not have specific rules for its elaboration, the only important aspect is the way in which the causes can be found. They are divided into 5 categories that are defined and known as the "5M" (Men, Machines, Methods, Measurements, Materials). Each branch of the diagram represents a category

| Detection | | |
|---|---|---|
| **Effect** | **Criteria: Severity of Effect** | **Rank** |
| Absolutely impossible | The design control doesn't detect a possible cause of failure or the subsequent failure mode, or there is no design control. | 10 |
| Very remote | Very remote possibility that the design control detects a possible cause of failure or a subsequent failure mode. | 9 |
| Remote | Remote possibility that the design control detects a possible cause of failure or a subsequent failure mode. | 8 |
| Very low | Very little chance that the design control will detect a possible cause of failure or a subsequent failure mode. | 7 |
| Low | Little chance that design control will detect a possible cause of failure or later failure mode. | 6 |
| Moderate | Moderate possibility that the design control detects a possible cause of failure or a subsequent failure mode. | 5 |
| Moderate high | Moderately high chance that design control will detect a possible cause of failure or later failure mode. | 4 |
| High | High probability that the design control detects a possible cause of failure or the subsequent failure mode. | 3 |
| Very high | Very good probability that the design control detects a possible cause of failure or a subsequent failure mode. | 2 |
| Almost sure | The design control detects a possible cause of failure or the subsequent failure mode. | 1 |

**Table 4.**
*Detection levels. Own elaboration based on [28].*

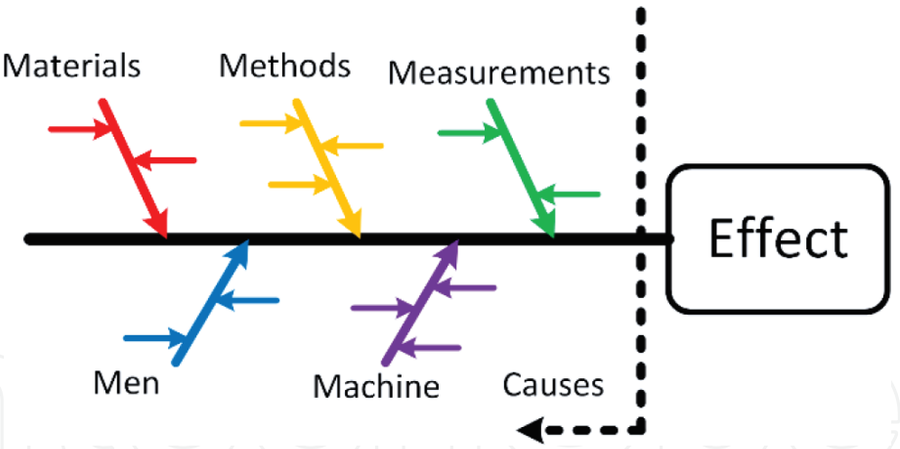



**Figure 4.**
*Ishikawa diagram. Own elaboration.*

and these in turn have sub-branches that represent the causes. The categories are described as follows:

- Men: anyone involved in the project.
- Machines: all equipment or tools used.
- Methods: from how the process is carried out to the specific requirements.
- Measurements: all the generated data that are used to evaluate the quality.
- Materials: raw materials used to produce.

Ishikawa diagram provides a methodology which may include all possible considerations and although it looks slightly different from the form it takes, it is very similar to the mental map where all ideas are puts together based on a group brainstorming [30].

*2.1.4 Fault tree*

A fault tree is a model that represents graphically and logically the various combinations of possible events, both defective and normal, that occur in a system that leads to the unwanted future event. The main advantage of the method is its systematization, since it allows determining the multiple factors that contribute to the failures. It is used for the qualitative analysis to determine the situation of risk, and for the quantitative analysis, which allows to determine the probabilities of event sequences. Generally, its elaboration is a complicated and slow task, since the first step is to determine the individual superior event, then to analyze the sub-events enough data [31, 32]. **Figure 5** shows the basic symbols used for the fault tree elaboration.

Next, a brief description for each basic symbol is given. In addition, **Figure 6** shows a basic fault tree example.

***Basic event***: represents the origin (commonly called root) of the fault or error, generally found in the lower part of the fault tree [33].

***Intermediate event***: represents the negative event and it is commonly located at the top of the tree, although it can also be found throughout the tree to indicate other events [32, 33].

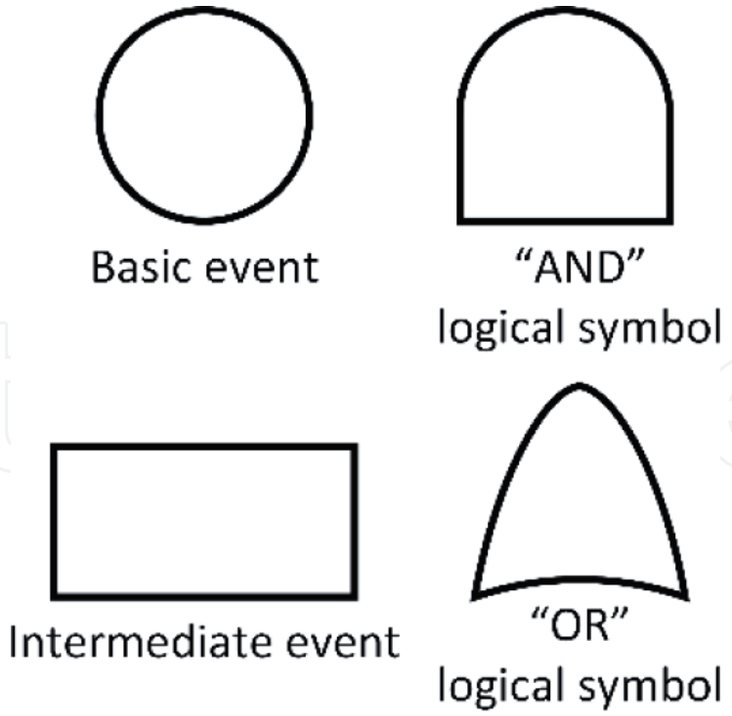



**Figure 5.**
*Fault tree symbols. Own elaboration.*

***¨AND¨ logical symbol***: represents a condition where the output occurs only if all the inputs occur in the result event, i.e., it will only occur if all the input events exist simultaneously [32, 33].

***¨OR¨ logical symbol***: condition where the event will occur only if one or any combination of the input events occurs [32].

## 2.2 Quantitative tools

Quantitative tools help to obtain a measureable prediction of the probability of occurrence of a failure or risk in such a way that they can be prevented [6]. These tools are usually from the field of statistics.

### *2.2.1 Gantt chart*

The Gantt chart is a very simple time charting tool that is quite effective for planning and evaluating the progress of projects [34]. **Figure 7** shows a custom Gantt chart. Basically, the Gantt chart is a bar graph placed on its side, where the horizontal axis corresponds to time and the vertical axis to related activities [35]. Among the advantages of the Gantt chart is that it clearly shows which activities are advanced or delayed, so it becomes an excellent communication tool, and almost everyone can read or build it [36]. Consequently, the Gantt chart can be used as a controller for project planning as it can ensure that all problems are addressed as required [37].

### *2.2.2 Critical path method*

The critical path method (CPM) is a technique based on a network diagram, similar to PERT, except for the handling of uncertainty in the context of activities, i.e., it is also used with a property, in addition to a unique time estimate for each activity [38]. This method is widely used in project management as it serves to

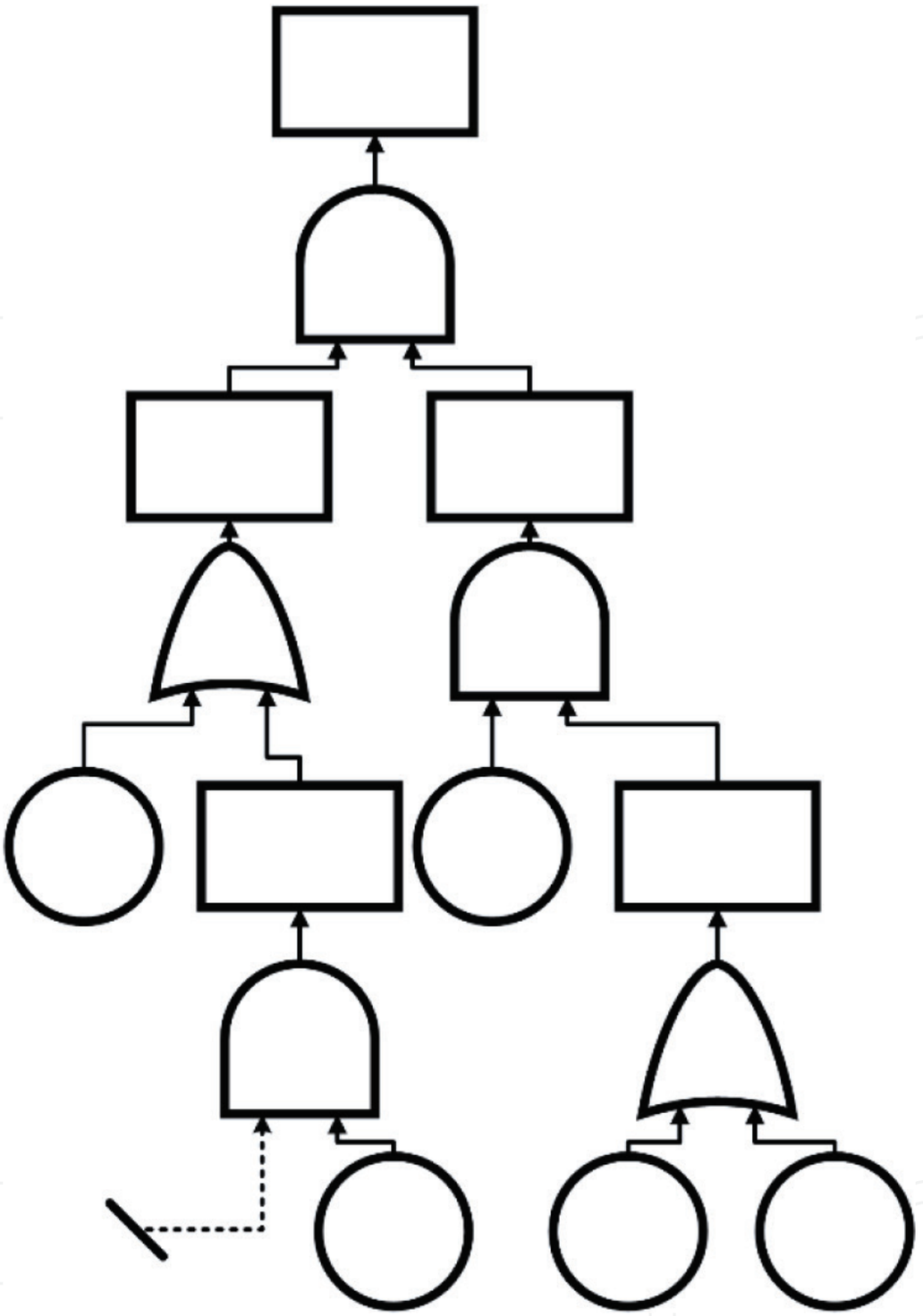


**Figure 6.**
*Fault tree example. Own elaboration.*

develop strategies and schedules using a one-time estimate for each activity that comprises the project [39]. An important benefit of this method is that it summarizes in a single document the general image of the entire project, which helps to avoid omissions, quickly identify contradictions in the planning of activities, achieving that the project is carried out with a minimum of stumbling. In particular, the method consists in the following stages: identify all the involved activities, establish relationships between the activities, decide which one should start before and which one later, construct a diagram connecting the different activities to their precedence relationships, define costs and estimated time for each activity, identify the critical path and slack activities, and finally, use the diagram to help planning,

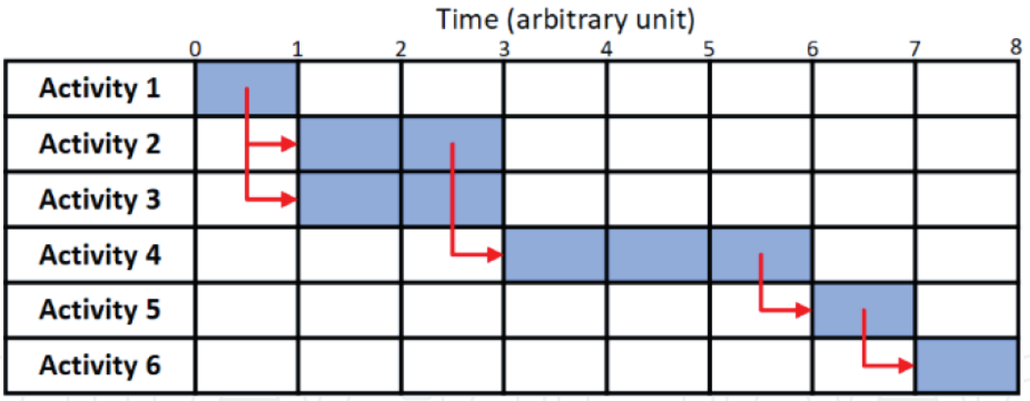



**Figure 7.**
*Gantt chart example. Own elaboration.*

monitoring and controlling the project. The elaboration of the critical path method consists of the following two cycles:

***Cycle 1*:** consists of the definition of the project, creation of a list of activities, matrix of sequences, time matrix, network of activities, costs and pending activities, understanding of the network, time constraints, economic resources and elasticity matrix [40].

***Cycle 2*:** consists of the execution and control of the project, it ends when the last activity of the project is running and, meantime, it can have adjustments based on the differences between the scheduled and expected activities [40].

### *2.2.3 Program evaluation review technique diagram*

The program evaluation review technique (PERT) is a method to plan and program a project that models the uncertainties for each activity using optimistic, probable and pessimistic time estimation [41]. A PERT diagram can be as simple or complex as needed, but it always involves three basic elements for its elaboration: circles where activities are written, lines that represent the direction of progress and dates that indicate the time of completion. The steps to perform a basic PERT diagram are: define the activities, indicate the necessary requirements before starting each activity and estimate the time required for each activity [42]. **Figure 8** shows a PERT diagram example.

The PERT diagram provides a methodology that is used to estimate the probability of completing the project for a specific duration. This methodology is based on calculating the standard deviation (difference between pessimistic and optimistic time, divided by 6, see Eq. (1)), variance for each activity and variance for critical activities to obtain the standard deviation of the complete project and finally the probability of success [38].

$$\text{standard deviation} = \frac{\text{pessimitic time} - \text{optimistic time}}{6} \tag{1}$$

The standard deviation for the project is the square root of the sum of the variances of the critical activities. Once obtained this value, the probability is determined by calculating the z value and using a probability table for multiple z values as Eq. (2) shows.

$$z = \frac{D - t_e}{\text{standard deviation for the project}} \tag{2}$$

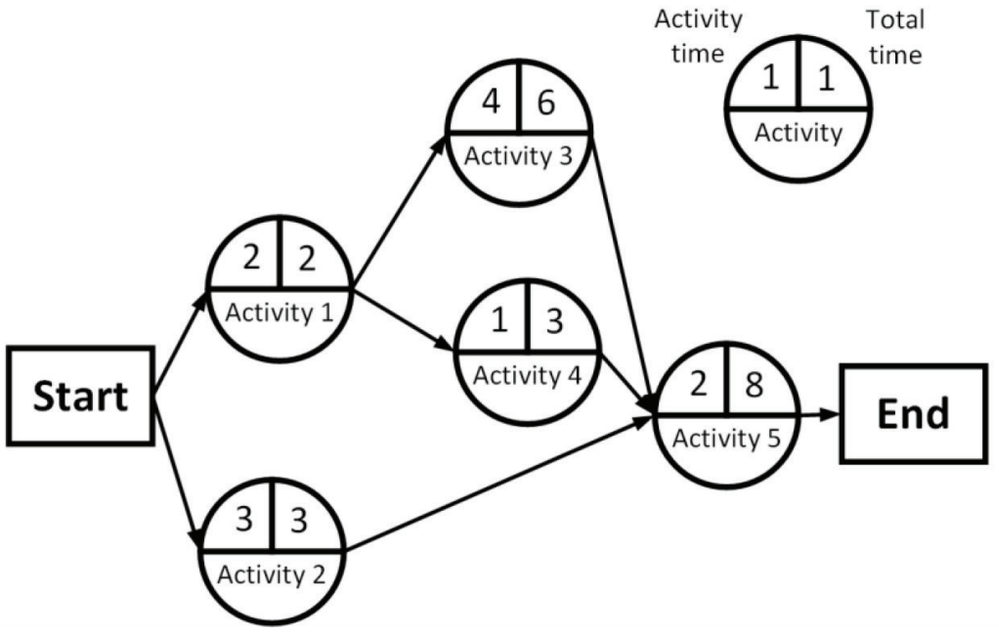



**Figure 8.**
*PERT diagram example. Own elaboration.*

where $D$ is the date on which the project must be completed and $t_e$ is the estimated termination in accordance with the critical path (maximum time required to complete the project).

## 2.3 Shortcomings of space systems management tools

The tools used in project management, despite being widely used, sometimes can omit important aspects of the project, i.e., they have important deficiencies and particular trade-off during their application. Occasionally, these shortcomings are not mentioned or known by the project team, so, the probability of success is decreased drastically. However, these tools are still very useful in project management because they can be applied to any type of project to have an orientation of what and how should be achieved. **Figure 9** shows some shortcomings of space systems management tools mentioned.




**Figure 9.**
*Shortcomings of space systems management tools. Own elaboration. Information retrieved from [6, 27, 35, 43, 44].*

Thus, if the shortcomings of these tools are found in a space project, they could cause great economic losses, since some parts of the project may be too important for an adequate development and performance. For example, when an Ishikawa diagram is applied for space projects, it is very important to consider all the possible causes of failures without exception to identify clearly critic activities. Thus, the previous analysis permits the team to act in case of any occurrence. Hence, it is necessary not to limit oneself to the moment in which it is being carried out and to dedicate the necessary time. In particular, the shortcomings of these tools are sometimes considered and a countermeasure to reduce them is to have a wider selection criterion on the personal who will be responsible for implementing the tool in the project. Otherwise, when these shortcomings are not considered, the results of the project may not be as expected or may simply be incorrect, even if the leader and personal believe that the project performance is adequate.

## 3. Proposed methodology

The methodology for the management of space projects proposed in this document is based on design thinking framework and it uses the tools mentioned in Section 2 (see **Figure 10**). To increase the performance of the proposal, the tools mentioned will work together using the brainstorming technique in different stages of the design thinking framework according to the shortcomings described. In addition, this methodology proposes the use of meetings that will serve as reviews between each stage of the design thinking method to prevent the progress to the next stage if something is unusual, i.e., review meetings will serve as filters based on a continuous feedback.

In particular, the methodology is described as follow:

- At stage 1 (definition) the Gantt chart is used to plan the overall project, from the activities order and time required until to define the person carries out such activity. Also, the Ishikawa diagram and FMEA can be used to contemplate critical activities. The purpose of the review meeting after stage 1 is to clarify the objectives to be achieved, so as not to move on to the next stages without having a unique specific definition. This stage is one of the most critical because the success of the project depends to a great extent on it.

- At stage 2 (research) the risk matrices, the fault tree and the Ishikawa diagram are used, since they will help from the first stages to identify possible causes of failure risk for the project. After stage 2, another revision meeting follows since it is important to verify that all possible failure causes have been considered by systems engineering tools.

- At stage 3 (interpretation) the PERT diagram and CPM are used to recognize the critical path of our project. At the end of stage 3, another review meeting is held since this is the intermediate stage of the project and making the meeting at this point helps us to follow the rest of the project along the best path.

- At stage 4 and 5 (ideation and prototyping) all tools could be used. Between stages 4 and 5 as well as after stage 5, review meetings are important because at these points the project is already taking shape and it is completely close to what will be its end.

- At stage 6 (evaluation) the FMEA can also be used to evaluate the possible causes of problems and identify how to control or eliminate them.

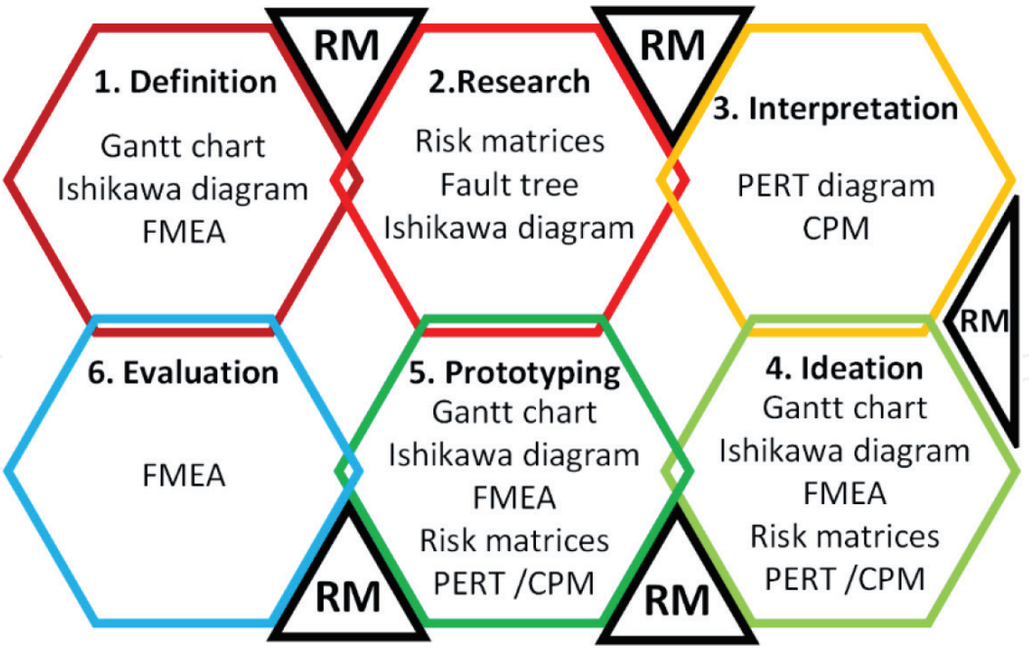



**Figure 10.**
*Proposed methodology stages. RM: Review meeting.*

- The final revision meeting it is essential because is necessary to ensure that everything that was done is correct. In addition, a feedback of the whole project is given.

The brainstorming technique could be used in all stages because it is a support tool. However, other tools can be used to complement or support all stages of the project. Finally, the conventional design thinking methodology presents an important disadvantage; unclear rules and statements were considered to determine the particular stage and future stage of a project. Therefore, our proposal uses management tools in different stages of the methodology proposed. In addition, it is possible to use Markov chain theory to determine the transition probability among the stages of the project.

## 4. Conclusions and future research

Conventional systems engineering tools were analyzed to be used in a design thinking framework for space project management. Each tool analyzed presents inherent shortcomings. In fact, although these tools are widely used in many engineering sectors, their trade-offs have not been investigated in deep to improve the overall project management using innovative countermeasures. Thus, the use of methodology proposed will help to make the conventional space systems projects management more efficient, because it will reduce the shortcomings of existing tools and to improve the prevention of possible failures causes as well as their effects. Although many high-end methodologies regarding the space project management are used around the world, our proposal is suitable for emerging countries and space agencies that require to optimize their resources to accelerate the aerospace industrial sector based on the academic and scientific regional contributions. In this context, the present proposal is being analyzed to be applied in a real space project, either for particular space products (e.g., antenna systems, attitude actuators and sensors, payloads, structures, solar panels and power systems, among others) or small satellites missions.

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